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SEWAGE SLUDGE

TREATMENT AND UTILIZATION OF SLUDGE

BY

ALEXANDER ELSNER

THE DRYING OF SLUDGE

BY

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TRANSLATED BY

KENNETH AND ROSE S. ALLEN

OPERATION OF MECHANICAL SEWAGE PLANTS

BY

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SLUDGE TREATMENT IN THE UNITED STATES

BY

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McGRAW-HILL BOOK COMPANY

239 WEST 39TH STREET, NEW YORK

6 BOUVERIE STREET, LONDON, E. C.

1912

PREFACE

With the rapidly increasing number of sewage treatment plants in the United States and the development of new methods, those interested in the subject will appreciate the valuable contribution to our literature on the troublesome subject of sludge contained in the following monographs by Dr. Elsner, Dr. Spillner and Mr. Blunk. The painstaking experiments and extended observations of these gentlemen, carried on under most favorable circumstances, enable them to speak with exceptional authority on this subject.

Dr. Elsner's paper—"Die Behandlung und Verwertung von Klärschamm"[1]—contains a large fund of data gleaned from experience with, and observation of, the more important German plants and those of England. The broad scope and thorough treatment are characteristic of the German investigator.

Dr. Spillner's paper, entitled "Die Trochnung des Klärschammes,"[2] is particularly valuable on account of the details of the results accomplished up to the end of 1909 in the operation of the plants of the Emschergenossenschaft, which are now receiving so much attention in this country. Dr. Spillner, as chemist, gives this information at first hand.

The third paper comprises Part III of a series written yet more recently by Dr. Spillner and Mr. Blunk on "Results of the Operation of Some of the Mechanical Sewage Clarification Plants of the Emscher Association."[3] This has been translated by Mr. Emil Kuichling, M. Am. Soc. C. E. The title of this paper is, "Examination of the Sludge, the Liquid in the Septic or Lower Chamber of the Deep Emscher Tanks, and the Water Drained from the Wet Sludge on the Drying Beds." As this of more recent date than the former article by Dr. Spillner the authors have had the advantage of further experience in the operation of tanks of the Emscher or Imhoff type, as well as of the comments and criticisms concerning their design or efficiency that have

[1] *Fortschritte der Ingenieurwissenschaften*, Zweite Gruppe, 24 Heft, Leipzig, 1910.

[2] *Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwasserbeseitigung*, 14 Heft, Berlin, 1911.

[3] *Technisches Gemeindeblatt*, Vol. XIII, pp. 313–377

been brought out in the intervening time. Moreover, Mr. Blunk, as operating engineer, adds to the discussion information derived from the engineer's point of view concerning their operation.

Although up to the present time sludge treatment has been accorded little attention in America as compared with Germany or England, this will be demanded more and more hereafter. Some really creditable work has been done in this direction, however, and it has therefore been thought desirable to add some notes on the characteristics of American sewages and on the more important results reached here in the treatment and utilization of sludge.

For the greater convenience of American engineers the measures given, unless otherwise stated, are those customarily employed in the United States: the gallon being the United States gallon of 231 cu. in.; the ton, that of 2000 lbs., etc.; but for the convenience of others the metric measure given by the authors of the first three parts are also stated.

Acknowledgment is here made of the courtesy of the city officials and others who have furnished data concerning the works under their charge and, in particular, of the valuable assistance rendered by Mr. Emil Kuichling in the translation of obscure passages in the original papers by Drs. Ing. Elsner and Spillner.

K. A.

NEW YORK, *November* 26, 1911.

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TREATMENT AND UTILIZATION OF SLUDGE

CHAPTER I

Introduction

The satisfaction felt in the more perfect methods of sewage clarification and their adaptation to different kinds of sewage has been diminished to an increasing extent by the question of the disposition of the sludge which accumulates in the vicinity of the works.

In 1857 the highest sanitary authority of England proposed that a part of the filth in sewage be removed before discharge into streams in order to prevent their further pollution and the intolerably unsanitary conditions resulting therefrom; and it was then that the sludge question first arose, *i.e.*, the question of its removal and the disposal of the filth separated from the liquid.

Formerly sewage had been disposed of in the easiest and cheapest way by discharging it into a stream, or, in a few instances, distributing it over the land for financial gain, while now the sludge was accumulated in the neighborhood of the plant without considering that the gain in sanitary conditions was more than offset by the putrefying masses of sludge in the thickly settled manufacturing towns, thereby impairing the health of the inhabitants.

The farmers did not make use of the sludge as had been expected. This was partly because they discovered that its value had been overestimated, and partly because of an increase in manufactures, whereby they were driven more and more to truck farming in those populous districts, requiring a more expensive fertilizer, which they were then able to pay for.

Two ways have been attempted to reduce this nuisance. A method was sought to make the sludge, which contained much lime after the prevailing chemical treatment, transportable by draining off a part of the water before putrefaction set in, in

order that its use might not be confined to the limited number of farmers in the neighborhood of the works, and so that, in this more portable condition, it might have an increased value commercially. Clarification processes were sought which would promise a smaller output of sludge while otherwise equally efficient.

The rapid spread of septic treatment may be attributed to an exaggerated idea of the reduction of sludge which was anticipated. A further advantage was the comparative infrequency of the objectionable process of cleaning required by this method. The introduction of biological methods, which seemed at once to solve the difficulty by means of the sludge-consuming activity of micro-organisms, was favored by the difficulty in caring for the annually increasing quantities of sludge due to chemical precipitation.

The assumption that the amount of sludge would be reduced by 70 per cent. or even 90 per cent., as had at first been expected, in septic tanks, was shown to be erroneous, nor was the difficulty of caring for the sludge removed by biological treatment; for even contact beds become clogged more or less quickly, according to the fineness of the material and the frequency of filling, and must then be taken apart so that the sludge can be washed away. With sprinkling filters, especially when made of coarse material, the necessity for taking them apart does not occur so frequently, but flakes of deposited matter are washed out of the beds, which usually necessitates the placing of a sedimentation basin in the line of the effluent conduit. It has been found that the greatest practicable preparatory clarification by sedimentation tanks may increase the cleansing power of bacteria beds by 1 1/2 or 2 times, while at the same time postponing a premature accumulation of sludge.

This is also true of sprinkling filters and intermittent land filters. Here it is especially the grease, animal fibers, hair and cellulose which form a felt-like surface sometimes 2 in. (5 cm.) thick, injuring the plant life, lessening the filtering capacity, and hindering the aeration of the soil. Removing this cover is expensive and much of the fertile soil is lost. Furthermore, much larger volumes of sewage can be delivered to the land after thorough preliminary treatment (English estimates give 5 times as much with chemical treatment, 10 times as much with biological treatment), a most important fact in consideration of the

decreasing area of available land and its increasing value accompanying the growth of cities. It is not only in sedimentation, septic treatment and chemical precipitation, as well as in screening plants and grit chambers where sludge naturally accumulates, but also in sprinkling filters, land filters and contact beds that it becomes a troublesome factor.

Two qualities render sludge particularly troublesome to both the technical employees and to those living near the plant, and also, on account of the high cost of removal, to the town authorities. These are the tendency to putrefaction, particularly in warm weather, and the contained water, which increases its volume and adds to the cost of transportation.

In particular its tendency to putrefy quickly in warm weather with a strong, disagreeable odor, which becomes a nuisance not only to the operatives at the works themselves, but also to the residents of the neighborhood, made a change ever more imperative. This is easily understood when one remembers that by far the greatest part of a city's filth is stored near the clarification plants. What large quantities are involved may be seen from the fact that in the 16 years from 1887 to 1903, 930,000 cu. yds. (711,000 cbm.) of solids were removed from the sewage of Frankfort. Here, indeed, as in most places, a further accumulation of sludge might be avoided by its use as a fertilizer; but the annoying odors already mentioned cannot thus be avoided since the great proportion of water calls first for its drying out in the air. Commonly, however, the demand for fertilizer is not great since, especially as in the vicinity of towns lacking a sewerage system, the supply of night-soil, with its higher fertilizing power, may supply the farmers' needs. Many examples made it clear that in planning clarification plants the greatest attention should be given to the disposal of the sludge. This was the case, not only in England, where the sludge nuisance appeared more pressing on account of the chemical treatment, which was preferred for its greater removal of sludge and for the enhanced value of the sludge itself due to the addition of lime, but also in Germany, where, decades later, similar conditions were reproduced on a smaller scale.

But even where it is easy to dispose of the sludge, whether dried or wet, there is occasion for further treatment. For, as this by-product is of small value and of considerable mass, there should be an effort to avoid its transportation and treatment,

especially by manual labor, which increases the cost to an unnecessary extent. What an enormous expense may result is seen in London, where about $238,000 (1,000,000 M.) is annually spent in carrying the sludge to sea in tank steamers.

In Leipzig, too, the annual expense of handling is about $7100 (30,000 M.), mainly for carting off the dried sludge.

Efforts to improve this condition have been made in two directions. One was to remove the sludge and to simplify and cheapen its transportation to drying beds or places of utilization, and in particular to avoid the unhygienic manual labor. One way to effect this is to give the tanks, wells and towers for sludge the best possible form; and, further, to install machinery and apparatus for the automatic removal of the sludge, or to operate the plant so as to produce the least possible amount of sludge with equal clarification.

Other experiments and attempts have been made to remove the water from the sludge more quickly and with less objection than by drying in the open air, or at least to improve upon this method, water being the greatest drawback to rendering sludge of value. Above all, it is desirable to retain the fertilizing properties of the sludge, its fats and calorific value, and in this way to reduce the cost of treatment, efforts which are important even from the agricultural standpoint. It is estimated that $143,000,000 (600,000,000 M.) are annually lost by failure to utilize the nitrogen in sewage, but one-tenth of which is used. Although these figures are theoretical and perhaps exaggerated, they should cause one to reflect.

These considerations for simplifying and improving sludge disposal and utilizing it, or at least attempting to do so, are of great importance to an engineer who is planning a disposal plant. Disregard of these matters has often resulted in costly alterations, or even a complete change of plan.

Any standardizing of sewage treatment should be strictly avoided and each plant designed with reference to the particular local conditions.

CHAPTER II

Sludge, Its Composition and Amount

By sludge is here meant all the residue which remains after treatment of city sewage by grit chambers, bar screens and mesh screens, tanks, wells, and towers, by plain sedimentation or chemical precipitation, septic tanks, contact beds or irrigation fields.

Its composition and amount depend upon:

1. The composition and volume of the sewage.
2. The manner of collection.
3. The method of treatment.
4. The operation of the plant.

1. The amount and composition of sludge, which consists mainly of the undissolved matter contained in the sewage, vary quite as much as the character of the sewage in different towns.

Even the amount differs very greatly. To mention but two examples, Paris sewage contains 1515 parts per million (mg. per liter) of undissolved material, but that of Hanover 270 parts per million (mg. per liter).

Those cities whose inhabitants have low standards of living and use but little water per capita, have a very concentrated sewage, and so, in general, a large volume of sludge.

Aside from this, the amount of trade wastes determines to a large extent the character of the sewage. This depends, not only upon the volume of the trade wastes, which sometimes surpasses that from domestic sources, but also upon the addition of certain substances, particularly free acids and salts of iron, which can convert undissolved into soluble material, and thus effect the amount and character of the sludge. Certain industries add substances which increase the putrescibility of the sludge or retard its drying, such as textile mills which give it a fibrous, felt-like character. Others add large quantities of grease which may determine the method of removal or treatment of the sludge. Other substances, particularly from metal works, act on the sewage and sludge as a disinfectant.

The daily change in the character of the sewage is of importance in plants where the sludge is removed during continuous sedimentation, particularly where it is carried immediately to the filter press for further treatment. Not only is its character changed but also its volume.

2. The system of sewerage is of importance in so far as the amount and character of the sludge is concerned, as considerably more mineral matter reaches the sewers in a combined system. The amount of this material again effects the character of the sludge, particularly its percentage of moisture. Large quantities of filth are washed in from the streets during heavy rains as also by the cleaning of asphalt and wooden pavements.

In towns where the streets are chiefly macadam and where no catch basins are provided, in order to collect as much of the filth as possible at one point outside the city, especial care should be taken, in planning the dimensions of the grit chamber and the means for cleaning it, on account of the large amount of mineral matter brought down.

If the sewage passes through pumping stations and long force mains or traverses long distances before it reaches the treatment plant, much of the suspended matter will be broken up, thus reducing the amount retained by the tanks and screens, a consideration of especial importance where the clarification is effected by these means only.

3. The greatest variation in the volume and character of the sludge is due to the method of clarification: that is, the method and arrangements by which the separable matter is removed from the sewage.

Not only is the amount of the sludge, but also its condition and composition, dependent on the efficiency of the process of clarification.

Detritus from Grit Chambers

The sediment removed by grit chambers is composed principally of inorganic matter. Its putrescibility, the most offensive quality of sludge, is therefore slight, as well as the amount of water contained. This varies from 35 to 60 per cent. It depends, aside from the manner of cleaning the grit chamber and the frequent stirring-up resulting therefrom, upon its content of organic matter, and this, again, upon the velocity of flow provided. Two

inches (5 cm.) per second should be the least. On the one hand the attempt should be made to keep the deposit as free as possible from putrescible organic matter in order to permit of its convenient disposal, its handling and transportation; on the other, it should be remembered that the mineral particles of the detritus carried to other parts of the plant form there an undesirable ballast which makes the care and utilization of the accumulated sludge difficult. For this reason the installation of a special grit chamber is seldom omitted.

Detritus from Screening Plants

The screenings from screening plants differ greatly both in amount and character. The meshes of the screen or the spacing of the bars may run from 1.0 in. (25 mm.) to 0.04 in. (1 mm.) according to whether it is desired to keep coarse matter from the sewage or sludge pump, or to secure the greatest possible clarification of the sewage.

The amount changes, also in the course of the day. As most of the coarser suspended matter consists of wastes from habitations the amount reaches its maximum at noon or soon after, and almost disappears by nightfall. This fact is of importance in the case of bar screens. The material is almost wholly organic and consists of scraps of meat, vegetables or fruit, cloth, hair, corks, wood and lumps of fecal matter.

Its composition varies so widely that it is impossible to give an average value. The amount of water contained is small, amounting to but 70 or 80 per cent. On account of its organic origin it is highly putrescible.

Sludge from Plain Sedimentation

Sludge formed by the process of sedimentation in tanks, well and towers consists of a semi-liquid, black mass which soon becomes offensive with much gas and foul odors. Its decomposition is accelerated by warm weather.

The amount of water in the sludge in tanks is usually 90 per cent., in wells and towers 95 per cent. and more, and is regulated by the manner of treatment.

In conjunction with the sludge from chemical precipitation and septic tanks, it produces the largest volume to be treated on account of the proportion of water contained. Therefore,

most of the efforts and treatment for the utilization of sludge aim at its removal.

Grease Contained in Sludge

Here we see the significance of the grease contained in sewage and also in the sludge as, on the one hand, this may interfere with the use of the sludge in agriculture and, on the other, has led to attempts for the recovery and utilization of the grease.

According to the experiments of Schreiber, the Berlin sewage contains 22 lbs. of grease per 1000 persons (20 g. per capita) per day, *i.e.*, 16.1 lbs. (7.3 kg.) per capita per annum. This corresponds to a quantity of grease in the sewage of from 0.01 to 0.026 per cent., most of which reappears in the sludge.

Also, in the settled sludge of other cities, as Frankfort-on-the-Main, Mannheim, Elberfeld and Cassel, the amount of grease is found to be from 15 to 20 per cent. of the dried material.

The Kremer apparatus shows much larger amounts of grease in the scum. In the Osdorf experimental plant, with an amount of water in the sludge from 81 to 86 per cent., they found from 9 to 6 per cent. of grease, or, referred to the dried material, as much as 49 per cent. In Charlottenburg, with the same apparatus, 12.8 lbs. of grease per cubic yard (7583 g. per cbm.) was recovered. This would give 500 lbs. (227 kg.) of grease from 7,925,000 gallons (30,000 cbm.) of sewage per day for the whole city.

Sludge from Chemical Precipitation

The sludge from chemical precipitation is similar in character to that from plain sedimentation but the quantity is much larger, which fact, taken in connection with its decreased value as a fertilizer on account of chemicals used in the process, has been to a great extent the reason for abandoning this method of treatment.

The large volume of sludge is explained by the more complete separation of the undissolved material by chemical treatment, and also by the addition of the precipitant.

It should be noted that 2086 lbs. of lime per million gallons (250 g. per cbm.) of sewage, which is often used in England, produces not only 0.55 lbs. (250 g.) of sludge but 5.52 lbs. (2500 g.) as the lime settles as sludge containing about 90 per cent. water.

Sludge from Lignite Process

The sludge obtained by this process is very full of water (95 per cent. or more) but can generally be easily pressed or dried in the air, as is done at Cöpenick, without putrefaction or the emission of unpleasant odors. The pressed sludge has but a faint musty smell and is non-putrescible.

Sludge from Septic Tanks

The same thing is true of the sludge from the septic tank, as this has gone through the process of decomposition in the tank.

This, too, has only a slight musty odor.

It has a granular earthy structure from decomposition, in contrast with precipitated sludge which, after the water is drawn off, has a fibrous, felt-like appearance.

The earthy character of sludge from the septic tank process aids in the removal of the water, enabling it to dry more rapidly. It is also more fluid, in comparison, in spite of the small amount of contained water—about 80 per cent.

All the data thus far given concerning the amount of water contained in sludge are averages taken from a large number of plants and are subject to certain variations depending upon the design of the plant and particularly upon the thoroughness of the mode of operation and the method of removing the sludge.

Digestion of Sludge

In the septic process one phenomenon has been much discussed, namely, the digestion of the sludge. That is to say, a diminution of the quantity of the sludge in such a manner that the dried solids contained both in it and in the effluent of the septic tank are less than the amount received. A reduction of 80 per cent. or more was anticipated by the introduction of the septic treatment and thereby relief from the troubles associated with sludge. The amount of suspended matter contained in the effluent must be considered in determining the percentage of reduction, and this is rather large. In different English cities, for example, it varies from about 35 parts per million (mg. per l.) at Salford to 244 parts per million (mg. per l.) at Birmingham. Moreover, the sludge becomes more dense in time and in this way loses a part of its water. In fresh sludge this is about 90 per cent. and in dried sludge 80 per cent., as has been noted; therefore the former has twice the volume of the latter.

Moreover, a part of the solids is transformed into gas and another part liquefies. This alone is to be considered in the reduction of sludge.

The amount of this in different English cities is as follows: Birmingham 10 per cent., Manchester 25 per cent., Leeds 30 per cent., Sheffield 33 per cent.

In Unna, also, where it was removed only once a year it was found to be but about 60 per cent. of the aggregate amount when removed weekly.

The reason for the difference between these several figures lies partly in the difference in the composition of the sewage, especially whether it is putrescible domestic sewage or whether it contains much impalpable mineral or other material not easily broken up, and partly in the different amounts of the solids contained in the effluent of the septic tank.

A certain amount of sludge reduction may always be expected after prolonged storage.

Sludge from Contact Beds

Sludge is also found in contact beds and its removal at stated intervals is necessary, depending on the extent of its preparatory treatment, the construction of the beds and their operation. The sludge that is washed out is of an earthy consistency, contains 60 to 75 per cent. water and is readily dried. As it is biologically digested it does not become foul later except in those cases where the beds are overloaded. It strongly resembles septic sludge. In sprinkling filters it contains, under certain conditions, a larger amount of organic matter, such as the larvæ of flies and mosquitoes, while in contact beds it contains earthworms and other worms.

Sludge on Irrigation Fields

Sludge sometimes appears on irrigation fields in the form of a layer of slime which covers the soil. It consists of cellulose and grease, prevents the admission of air and sewage and must be removed with a spade. This slime can be avoided by installing sedimentation tanks.

The differences in sludge obtained by the various kinds of treatments mentioned correspond also to its chemical composition, so that there is little practical value in giving definite limits to the amount of each ingredient of which it is composed.

In order to present a general idea of the matter some analyses showing results obtained with different methods of treatment are here given. Later some materials will be considered more fully which give to sludge a certain fertilizing value.

ANALYSES OF SLUDGE IN PER CENT.

	Sludge from plain sedimentation Frankfort-on-Main		Sludge precipitated by		Septic Sludge. Stuttgart	Sludge from contact beds. Tempelhof
			Lime	Sulphate of iron and lime		
	Wet	Dry	Frankfort-on-Main			
Water	91.07	....	90.85	80.96	77.3	74.2
Organic matter	5.08	57.00	4.15	13.31	7.35	16.5
Nitrogen contained	0.23	2.85	0.31	0.10	0.4	0.6
Inorganic matter	3.85	43.00	5.00	5.73	15.35	9.3
Phosphoric acid contained.	0.23	2.85	0.07	0.02	0.4	0.5
Potash	0.05	0.56	0.02	0.007	0.1	
Oxide of iron	....	....	....	....	....	2.0

Influence of the Manner of Treatment

4. The management of the plant has a marked effect on the quality of the sludge, especially the amount of water contained, and therefore upon the total volume.

As already shown, this is the case to a certain extent with grit chambers. A frequent cleaning out of the sludge, possibly with dredges, causes a stirring up of the deposit, thus mixing it with the sewage, while in plants where the cleaning is done at longer intervals after cutting out the grit chamber, which is ordinarily divided into compartments built side by side, the grit deposits more firmly and contains less water.

This difference is not very important in consideration of the comparatively small quantity of deposit in the grit chamber, its easy handling and its inoffensive character.

In settled sludge, on the other hand, the quantity of water is of great importance, as its large amount may readily result in a nuisance on account of its unforeseen increase as well as from the greater cost of the transport and disposal of the increased volume.

In considering the influence of the contained water on the amount of sludge it should be noted that 1.3 cu. yds. (1 cbm.) of sludge having 80 per cent. moisture contains 7 cu. ft. (200 l.) of

dried solids, while 1.3 cu. yds. (1 cbm.) of sludge having 95 per cent. moisture contains 1.75 cu. ft. (50 l.) of dried solids; therefore the amount of the contained solids is as 4 :1. A given volume of sewage from which the suspended matter is removed and dried produces in the first case 4 times that in the last. The amount of this material alone corresponds to the degree of clarification, but not to the total volume of the sludge.

Sludge contains the most moisture, 95 per cent. and over, in plants where it is removed continuously, as in this case it is always kept in motion and cannot settle.

In clean sedimentation tanks also, *i.e.*, where great care is taken to prevent the settled sludge from putrefying, the water content is large, especially in summer, as the sludge must be removed frequently.

In order to reduce the volume of sludge it may be allowed to remain longer and partially digest when the effluent from the sedimentation tank is given subsequent treatment, possibly on contact beds of irrigation fields. Sludge is then produced with 85 to 90 per cent. less moisture.

It is assumed that the sewage does not contain substances from industrial plants which inhibit putrefaction, so that it is at most a question of reducing the volume by consolidation from prolonged settling.

That the consolidation of sludge has an effect on its water content is seen in the Emscher tank, where the sludge at a depth of 36 ft. (11 m.) contains 70 per cent. moisture and at 29.5 ft. (9 m.) 75 to 80 per cent. This occurs less in ordinary tanks, with their less depth of sewage and sludge, than in wells and towers.

The velocity of the sewage also affects the amount of water in the sludge. This has been demonstrated by the experiments of Steurnagel at Cologne. It was found that the slower the velocity in the tank the greater the volume of sludge.

The experiments showed that in 264,170 gallons (1000 cbm.) of sewage with a velocity of 0.156 in. (4 mm.) per second the result was 5.28 cu. yds. (4.04 cbm.) of sludge, with 95.57 per cent. of moisture and 4.43 per cent. of dry material; with .78 in. (20 mm.) per second velocity, 3.23 cu. yds. (2.47 cbm.) of sludge, with 92.87 per cent. of moisture and 7.13 per cent. of dry material; with 1.56 in. (40 mm.) per second velocity, 2.41 cu. yds. (1.84 cbm.) of sludge, with 91.34 per cent. of moisture and 8.66 per cent. of dry material. An examination of these figures shows that the

volume of sludge is greatly increased by diminishing the velocity, but that the amount of the dried material is less, so that after all a much larger volume is produced [twice as much by .16 in. (4 mm.) per second velocity as with 1.56 in. (40 mm.)] without improving the clarification; for the amount of the dried material removed is as 17.9:15.9. These experiments, however, only lasted one day. In practice one can count on a greater consolidation of water and sludge with a velocity of 0.16 in. (4 mm.) per second.

The explanation of the result of this experiment is that with the greater velocity the finer particles of sediment, which are contained in a large quantity of water but which altogether comprise but a small amount of dried solids, are carried into the receiving stream.

If sedimentation tanks are used intermittently, *i.e.*, if the sewage is retained in them for some time after filling, possibly from 2 to 6 hours, and is then drawn off, clarified, the amount of settled sludge is less than with a continuous flow. Sludge is always stirred up in refilling which does not settle again but passes out in the effluent. It does not pay to clean out the comparatively slight deposit from every filling, in which way this objection could be met.

In London at Barking the proportion of sludge derived from intermittent treatment (with 2 hours' resting) to that from continuous flow is as 1 : 3, but this is in part due to the short time allowed for resting. The difference in the volume and consistency of the sludge is marked between the operation of several tanks in parallel and in series.

In the latter case a large amount of thick, viscous sludge is deposited in the first tank and a fine, greasy mass of less volume in the last. As cleaning out is therefore required less frequently in the latter, this system and also the sludge more nearly resemble those of septic treatment plants.

In planning for the removal and utilization of sludge and the sums to be expended, the method of clarification should be considered from the beginning.

Amount of Sludge

It is also desirable to possess more information concerning the amounts of sludge deposited by the different methods of clarification.

It is impossible to give final figures or formulæ by which the quantity of sludge to be expected may be exactly estimated, for this must vary within very wide limits for the reasons already stated. Exact values can only be ascertained by experiments with the sewage in question, which should always be made in the case of large plants and especially where the sewage shows any peculiarity.

However, we can usually judge of the quantity of sludge to be expected from the amount of suspended matter in the sewage.

In this way Büsing, starting with an amount of suspended matter of about 700 parts per million (g. per cbm.) and a ratio of mineral to organic matter of 2 : 3, knowing the volume of the sewage and considering the amount of matter retained by catch basins, etc., estimates an amount of suspended matter equal to 1/1000 the volume of the sewage. The limiting values he states as 1/750, from a rather concentrated sewage, to 1/3000, where water is liberally used. This corresponds to 0.076 to 0.307 cu. in. of dried material per gallon (0.33 to 1.33 l. per cbm.) or 1.63 to 6.58 cu. yds. sludge 90 per cent. water per million gallons (3.3 to 13.3 l. per cbm.) and 0.43 to 1.74 cu. yds. per 1000 persons (0.33 to 1.33 l. per cap.) daily with a water consumption of 26.4 gallons (100 l.) per day. With an assumed average of 1 to 1500 for normal sewage the last two values would be 33.2 cu. yds. of sludge per million gallons (6.71 l. per cbm.), or 0.88 cu. yds. per 1000 persons (0.67 l. per capita) per day.

These values agree well as to the contained moisture with the figures of Imhoff (*Proceedings of the Royal Experiment Station*, Vol. VII) in which, from many analyses of sludge in England and Germany, the amount of dried material in sewage was established at 2.1 oz. (60 g.) per capita per day, when including storm water but not industrial wastes. This value gives, with an amount of water in the sludge of:

95 per cent. $2.1 \times 20 = 42$ oz. $(0.06 \times 20 = 1.2$ l.) sludge per capita per day.

90 per cent. $2.1 \times 10 = 21$ oz. $(0.06 \times 10 = 0.6$ l.) sludge per capita per day.

80 per cent. $2.1 \times 5 = 10.5$ oz. $(0.06 \times 5 = 0.3$ l.) sludge per capita per day.

We may approximate the same result by assuming an amount of suspened matter of 17.5 to 35 grains per gallon (300 to 600 mg. per l.), as is the rule with city sewage in Germany. With a

specific gravity of 1.1 we obtain 12.6 to 25.2 cu. in. per cubic yard (0.27 to 0.54 l. per cbm.) of dried material. As the larger floating substances are not included in the analyses this figure should be somewhat greater, so that 14 to 28 cu. in. per cubic yard (.3 to .6 l. per cbm.) of sludge containing 90 per cent. water may be expected.

In estimating these values no account is taken of a partial elimination of the solid matter in the clarification plant. The efficiency of the method of clarification is therefore to be taken into account.

These methods of estimating are valueless, possibly in the case of grit chambers, but particularly with screening or contact bed treatment. Here one must trust to experience and experiment. It is in any case of greater value to consider experience with the plants of towns where the conditions are similar than to depend upon theoretical calculations of the sludge to be expected.

AMOUNT OF DETRITUS FROM GRIT CHAMBERS AND SCREENS

Place	American measures		Metric measures		Method employed
	Cu. yds. per million gallons sewage	Cu. yds. per 1000 inhabitants per day	Liters per 1000 cubic meters sewage	Liters per 1000 inhabitants per day	
Leipzig	0.067	....	13.5	....	Coarse screening.
Charlottenburg	....	0.014	....	11	Grit chamber and screening.
Hamburg	0.826	0.056	167	43	Grit chamber and screening.
Ohrdruf	....	0.079	....	60	Grit chamber and screening.
Schöneberg	0.643	0.021	130	16	Grit chamber and screening.
Marburg	....	0.027	....	21	Grit chamber.
Marburg	....	0.022	....	17	Screening.
Frankfort-on-Main	0.643	0.038	130	29	Grit chamber.
Frankfort-on-Main	0.643	0.038	130	29	Screening.
Cologne	0.356	....	72	....	Grit chamber.
Cologne	0.905	....	183	....	Screening.
Elberfeld	0.426	0.025	86	19	Grit chamber.
Elberfeld	0.639	0.037	129	28	Screening.
Hanover	1.069	0.033	216	25	Grit chamber.
Dresden	0.149	0.007	30	5	Grit chamber.
Dresden	0.500	0.022	101	17	Riensch disc.
Munich-Gladbach	0.371	0.076	75	58	Screening.

The following tables give some results of the amounts of sludge obtained by various processes. The figures are obtained partly from reports and partly by direct information furnished by city authorities.

The amounts may be estimated per million gallons of sewage or per capita per day. The first method is used in towns where much of the sewage comes from manufacturing concerns, while the latter affords a better comparison where these are absent, because the different volumes of water used are eliminated.

It is further to be noted that in estimating the separate quantities the volume of sludge is usually ascertained quite accurately by the mark of the surface level in the tank, by the contents of the vacuum receiver or the sludge-press, or that of the drying bed, while, on the contrary, the volume of the clarified sewage in a specified period, especially in towns with combined sewerage, is usually not closely enough ascertained.

The results with these methods naturally vary greatly, especially with bar screens and mesh screens, on account of the difference in the size of the mesh and the spacing of the bars; but this is so with regard to grit chambers also, although in less degree, on account of the different velocities and other reasons already given.

AMOUNT OF SLUDGE FROM SEDIMENTATION TANKS

Place	American measures		Metric measures		Method of clarification
	Cu. yds. per million gallons sewage	Cu. yds. per 1000 persons day	Liters per cubic meter of sewage	Liters per capita per day	
Frankfort	16.3	0.930	3.3	0.71	Tanks.
Bremen	10.9	0.655	2.2	0.50	Tanks.
Hanover	9.9	0.301	2.0	0.23	Tanks.
Mannheim	10.9	0.877	2.2	0.67	Tanks.
Munich-Gladbach	12.4	2.620	2.5	2.00	Tanks.
Cassel	23.8	0.628	4.8	0.48	Tanks.[1]
Brieg	17.8	0.498	3.6	0.38	Wells.
Stargard	37.1	0.589	7.5	0.45	Wells.
Culmsee	123.8	0.877	25.	0.67	Tanks.
Langensalza	123.8	2.188	25.	1.67	Wells.
Leipzig	23.8	....	4.81	....	Primary contact beds.
Leipzig	0.8	....	0.16	....	Secondary contact beds.
Failswerth	2.8	0.092	0.56	0.07	Secondary contact beds.

[1] Without grit chambers and screens.

With grit chambers we estimate 0.37 to 0.75 (average 0.50) cu. yds. per million gallons [75 to 150 (average 100) l. per 1000 cbm.] of sewage and possibly 0.013 to 0.026 cu. yds. (10 to 20 l.) per 100 inhabitants daily. The same figures are to be used for bar screens. They are of course not correct for simple coarse bar screens which are only intended to keep coarse material from the pumps or plant. The amounts for these are much less, although with large screening plants they increase somewhat.

In the larger German plants the amount of sludge is fairly uniform. It is about 10 to 25 cu. yds. per million gallons (2 to 5 l. per cbm.) or 0.39 to 1.31 cu. yds. per 1000 persons (0.3 to 1.0 l. per capita) per day. These differences result from the causes already mentioned, but above all from the water contained in the sludge. Therefore the places mentioned in the tables employing clarification by wells have comparatively large amounts of sludge. For example, the high figures for Langensalza result from the continuous removal of fresh sludge. In Culmsee, on the other hand, the separate system exists and the sewage is fairly concentrated. Preliminary treatment by contact beds gives values similar to sedimentation, special weight being laid upon the greatest possible previous removal of suspended matter in order to protect the beds. Subsequent treatment, which is only used with sprinkling filters, on account of the particles of deposit frequently washed out, naturally shows but a small amount of sludge.

AMOUNT OF SLUDGE FROM SEPTIC TANKS

Place	American measures		Metric measures	
	Cubic yards per million gallons sewage	Cubic yards per 1000 persons daily	Liters per cubic meter of sewage	Liters per capita per day
Manchester	12.0	0.62	2.43	0.47
Accrington	7.9	....	1.6	
Colne	7.4	0.18	1.5	0.135
Hampton	4.36	....	0.88	
Birmingham	16.85	....	3.4	
Stuttgart	18.6	0.50	3.75	0.38
Merseburg	8.2	0.10	1.65	0.08
Müllheim	13.8	0.46	2.0	0.35
Unna	9.9	0.26	2.0	0.20
Leipzig[1]	7.3	....	1.47	
Emscherbrunnen	....	0.13–0.33	....	0.1–0.25
Halberstadt	47.5	1.26	9.6	0.96

[1] Preliminary biological treatment in experimental plant.

With septic tanks the amount of sludge produced is less the more complete the septic action (Merseburg). Where the sewage is chiefly domestic and without storm water, which always adds much mineral matter, the amount is about 0.13 to 0.26 cu. yds. for each 1000 persons (0.1 to 0.2 l. per capita) daily, or 7.4 to 12.4 cu. yds. per million gallons (1.5 to 2.5 l. per cbm.) of sewage. In the other case, as well as in the presence of much trade waste, the limit is increased to about 0.39 cu. yds. per 1000 persons (0.3 l. per capita) per day, or to 17.3 cu. yds. per million gallons (3.5 l. per cbm.). Therefore many of the English cities show much

AMOUNT OF SLUDGE FROM CHEMICAL PRECIPITATION

Place	American measures		Metric measures		Precipitant
	Cubic yards per million gallons sewage	Cubic yards per 1000 persons daily	Liters per cubic meter of sewage	Liters per capita per day	
Chorley...	79	3.64	16	2.78	Aluminoferric
Hendon....	69	2.98	14	2.27	Aluminoferric
Lichfield. ...	29.7	....	6	......	Aluminoferric
Sheffield.....	13.4	0.54	2.7	0.41	Lime
Bury........	74	2.19	15	1.67	Aluminoferric
Guildford....	111.9	4.01	22.6	3.06	Aluminoferric
Glasgow.....	42	.....	8.5	......	Lime and sulphate of alumina
London.....	32.2	1.66	6.5	1.27	Lime and sulphate of iron
Leipzig.......	24.1	.80	4.87	0.61	Oxide of iron
Essen......	19.8	....	4.00	....	Lime

larger amounts of sludge. In Halberstadt the high figure is attributable to the limited amount of digestion as the sludge is removed here every 8 weeks.

Chemical treatment produces a varied amount of sludge depending upon the process employed and the amount of precipitant used, as the latter produces a large volume of sludge containing much water. Thus, 1.71 grains of lime per gallon (100 g. per cbm.) of sewage, if the precipitation were complete, would give 2.2 lbs. (1000 g.) of sludge with 90 per cent. moisture. But often .44 lb. (200 g.) to even 1.1 lbs. (500 g.) of precipitant are added separately. The increased clarification effected by sedimentation, possibly 75 to 80 per cent. of the suspended matter as compared with 60 to 70 per cent. by mechanical methods,

results in larger deposits of sludge. In general the amount is 25 to 50 cu. yds. per million gallons (5 to 10 l. per cbm.) of sewage. The low efficiency observed at Sheffield is explained by the fact that one-third of the sewage there is wash water.

The lignite treatment, which is closely allied to chemical treatment, removes yet greater amounts of sludge, 100 to 125 cu. yds. per million gallons (20 to 25 l. per cbm.) of sewage, partly because a very watery sludge is obtained, partly because the lignite and sulphate of alumina increase the volume greatly by the absorption of water. At Cöpenick on the other hand, where the sludge is obtained by drying out in the tanks to about 60 per cent. moisture, they get 12.5 cu. yds. per million gallons (2.5 l. per cbm.), or 1.18 cu. yds. per 1000 inhabitants (0.9 l. per capita) daily.

From the data given the amount of sludge to be expected may (in spite of some considerable differences) be estimated with sufficient accuracy for a given size of plant and the arrangements for its treatment and utilization.

Chemical treatment gives the greatest amount of sludge and has, therefore, been abandoned in many cases, while the septic tank gives the least. The rule applies to all methods, that the more thorough the purification the greater the resulting amount of sludge.

CHAPTER III

THE REMOVAL OF SLUDGE FROM CLARIFICATION TANKS

A well considered plan for removing the sludge from the tank and for its transport to places where further drying or treatment is carried on, is of great importance; for upon this rests the efficiency of various methods of treatment. Moreover, foul odors may in this way be minimized, if not entirely avoided, and large sums of money saved, especially in wages.

The plants and their details, therefore, vary very greatly and in general must be adapted to the methods of cleaning and of operation as well as to the topographical conditions.

The general principles to be observed in the treatment of sewage may be summarized as follows:

1. The more frequently sludge has to be removed and the larger its amount, the greater the attention that must be given to the matter and the greater the cost in any given case.
2. The condition of the sludge which is favorable for its later use must not be altered to its detriment in removal.
3. The removal of sludge must be accomplished with the least possible work.
4. This should be effected, so far as possible, without manual labor.
5. The removal should be as complete as possible.
6. With mechanical appliances it is important that all parts should be as simple as possible, especially movable parts, and that their location should be above water.

Referring to 1, the periods of cleaning are largely dependent on the method employed.

The removal of detritus from grit chambers usually takes place after the receptacles provided for it are filled, in order to avoid encroaching on the waterway and preventing insufficient sedimentation. A daily cleaning is only required where the amount removed is very large, as otherwise excessive dimensions for the grit chamber would be necessary, and this removal should then be by mechanical means.

With mesh screens and bar screens the detritus should, naturally, be constantly removed. Here, too, the removal in large plants is mechanical and automatic.

The intervals between the removal of sludge from semimentation tanks depend on the putrefaction of the material contained. This is controlled by the nature of the sewage and also by the temperature. Therefore the sludge may remain in the tanks 3 to 7 days in summer, 8 to 12 in winter. In chemical treatment these periods can be increased, especially when this method interferes with putrefaction. At Leipzig, *e.g.*, the sludge is drawn off every 10 to 20 days.

In septic tanks the sludge should be removed at much longer intervals. Its storage is here the important matter. With small installations removal need only take place from one to two times a year, in larger ones very one to three months. In general, an infrequent removal should be aimed at, as only in this way can the advantage of the septic tank be fully realized; for the amount is diminished by long storage, as has already been mentioned, and it also becomes less offensive. In any case an increase of suspended matter in the effluent caused by the accumulation of deposit and a resulting increase of velocity, indicate the time for cleaning. Another method, and one to be recommended in large plants with large volumes of sludge, is to draw off a part at shorter intervals during operation; while the main cleaning should be done in the fall and spring, especially where it is used as a fertilizer. When the removal is made, as at Leeds, through plug valves at the bottom, the result is the thickest and most thoroughly digested sludge and an objectionable interference with its free flow is prevented. Moreover, the tank is in continuous use and the sludge chamber can accommodate smaller volumes (Emscher tanks).

The intervals between cleanings in contact beds are so varied, according to their construction and demands, that no figures can be given.

The amounts of sludge from the different processes are given in the previous chapter.

As to 2, the favorable condition of the sludge, especially the small amount of water contained, must not be altered in its removal. If sludge from septic tanks, for instance, must be stirred up so as to be removed by pumps, the proportion of water, and consequently the entire volume, is increased, although

the water is given off again more readily on account of its composition than in plain sedimentation. In such cases sludge from the combined system leads to better results by drawing off the upper dilute layer by pumps, while the lower, settled layers are excavated, as in Unna. Sludge from plain sedimentation also contains more moisture where the stirring process or flushing pipes are used.

With the Kremer apparatus, where the sludge of the bottom layer contains but 85 per cent. of water or less (as here the grease and cellulose particles which attract a large amount of moisture are removed), this preservation of the favorable consistency of the sludge in its removal is most important.

Where the fine greasy material is removed separately by being passed through several tanks, the ability to keep it separate is desirable in order to work it over into grease, or else to bury it wet, while the coarser portion can be dried.

3. The work of disposing of sludge can often be greatly lightened by an intelligent use of the land. The places for drying sludge should therefore be located as low as possible in order to permit of its discharge from the tanks by gravity. This is especially desirable where the tanks are elevated above the surrounding land on account of an unfavorable soil for foundation and ground water (Rheydt) or where the entire plant is on sloping ground (Siegen).

Much may also be gained by a favorable arrangement of the ground plan of the separate parts, such as tanks, sludge wells, pumps and beds and apparatus for drying sludge.

As sludge containing much sand does not flow so readily and therefore demands a steeper slope in the bottom of the tank and in the pipes, it is advisable to place a good grit chamber for its interception. The suction of the pumps will then be more efficient and erosion lessened.

Much labor can be saved by forethought in designing the tanks for the removal of sludge. The use of mechanical apparatus, such as will be described later, will be of advantage in certain cases.

4. In spite of the large numbers of bacteria in sludge (over 11,000,000 per c.c. were found in one English examination of fresh sludge) the number of pathogenic germs is small. Therefore there is but little illness among the employees of these plants that can be traced to them. There is, however, some possibility

that the germs of contagious diseases in a city may exist in the sewage and sludge in large numbers until they are sufficiently disinfected.

For this reason, and because the exhalation from the sludge as it putrefies, as it almost always does in summer, are detrimental to the health of the workmen, their personal contact with the sludge should be avoided. The high wages required to get this dirty and unpopular work done can also thus be saved.

5. When portions of putrescent material remain in the tanks after the removal of sludge, the fresh sewage entering becomes contaminated and in a few hours septic. The bubbles of gas which form in septic tanks cause particles of sludge to rise and then pass out in the effluent or adhere to the contact beds, which may be inserted subsequently, hastening the process of sludging. In this connection all devices for drawing off the sludge from below the surface, and whose proper operation, therefore, cannot be observed, should receive careful supervision.

Formerly but little weight was attached to this matter in England, and as the outflowing liquid became putrescent and carried off larger flakes of suspended matter, plain sedimentation tanks were abandoned in favor of chemical precipitation.

If particles of sludge remain for any length of time in the tank they become compacted and their loosening and removal, perhaps by flushing nozzles or by stirring, always becomes more difficult.

6. It is unnecessary to point out that the principles applicable to all hydraulic work—that of providing mechanical details of the greatest simplicity and strength and locating their moving parts so far as practicable above water—are especially important in dealing with sewage and sludge. One favorable quality in sewage is to be noted: that the contained grease acts in many cases as a lubricant on the moving parts with which it comes in contact.

Removal of Detritus from Grit Chambers

Detritus is most frequently removed by suspending operation and cleaning it out with a shovel by hand after the sewage has been pumped off. For this purpose it is necessary to divide the grit chamber. A further division is sometimes made in the effort to maintain the most favorable velocity for depositing the mineral

matter by changing the flow of sewage by operating or cutting out the different units.

In smaller plants the deposited material is often collected in buckets set in a steeply sloping pit and these are lifted out by cranes. Larger plants are often provided with bucket dredges. These can be stationary provided the bottom has a steep slope (1:1) toward the dredge, but the movement in a vertical direction must be sufficiently great for it to be taken entirely out of the sewage after being used. This is necessary to avoid obstruction to the current of the sewage and to prevent the rusting of the bearings. In order to provide a steeper slope to the end walls with a greater length to the grit chamber it is advisable to pass the chain for the buckets over two pulleys, as in Figs. 1 and 2, as is done in Manchester. With a shallow pit the dredge must move horizontally. Sharp angles between bottom and side walls should be avoided, as these will not be reached by the dredge and facilitate deposits of decomposing sludge. Cleaning may then take place during operation, as at Frankfort and Elberfeld. With very fine sand this may cause trouble, as it will be stirred up

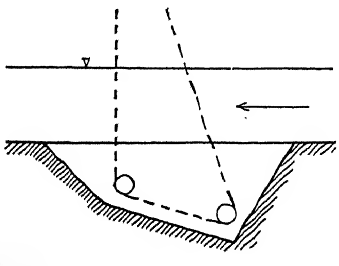


Fig. 1.

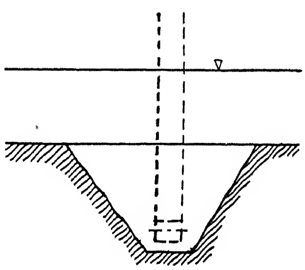


Fig. 2.

Figs. 1 and 2.—Arrangement for cleaning grit chamber.

and washed out by the dredging. For this reason the dredge was abandoned at Marburg. In place of the bucket-and-chain dredge a clam-shell dredge may be used, but, in order to prevent injury to the bottom, only when the plant is not in operation.

On account of the depth of detritus in grit chambers, its removal by pumps or steam ejectors, as was attempted at Düsseldorf, is not feasible, as the sand is mixed with water which then has to be again separated. At Merseburg, on the other hand, a Wegner patent portable suction pump was successfully employed, which will be spoken of later.

The mechanical devices for the removal of detritus from mesh screens and bar screens, which are usually an intrinsic part of the plant, will not be particularly mentioned here. Further particulars may be found in Dunbar's "Principles of Sewage Treatment"[1] and Schmeitzner's "Clarification of Sewage."[2] In smaller plants the cleaning is usually done by hand with rake or spade.

Contact beds are taken apart for cleaning, and the material freed from deposit by rinsing or washing by hand or by machines, such as are used for gravel filters.

Removal of Sludge from Tanks, Wells and Towers

The question of removing sludge from tanks, wells and towers in sedimentation plants or from chemical precipitation tanks is of great importance. It is a question involving much larger volumes and also a more frequent removal made necessary by these methods of clarification.

We may make a distinction at this point between (a) removal with interruption of operation, and (b) removal during operation.

a. Removal with Interruption of Operation

In this method the tanks are allowed to remain quiet—for tanks are almost always used in this method—for 1 or 2 hours after cutting off the supply. The clarified liquid above the sludge is then discharged into the outfall through an outlet controlled by gates or stop-planks. With a fixed overflow weir there is sometimes a special by-pass channel with a controlling valve. The turbid liquid which then remains in the tank above the sludge must usually be drawn off by pumps or a vacuum receiver, and conveyed to the influent conduit for a second clarification. Where there are several tanks it can be brought through a sufficiently deep connecting channel to a clean empty tank, in this way saving some cost. This tank is then filled with unsettled sewage and the process continued.

The drawing off of the turbid liquid must be done in such a way that it is removed as completely as possible down to the underlying layer of sludge without stirring this up. For this purpose a

[1] "Clarification of Sewage," by Dr. Ing. Rudolph Schmeitzner. Translated by A. Elliott Kimberly. Eng. News Pub. Co., N. Y., 1910.

[2] "Principles of Sewage Treatment," by Prof. Dr. Dunbar. Translated by H. T. Calvert. J. B. Lippincott Co., Phila., 1908.

movable weir, of which there are various types, may be used, or channels at different levels, such as are patented by the firm of Geiger in Karlsruhe, and have been furnished by them for Elberfeld. Here there is a drum whose casing is perforated by short spiral slits placed behind an iron plate with a vertical slit set in the wall of the tank. The liquid is gradually drawn off to lower levels by the rotation of the drum containing the slits which overlap those in the plate at different elevations.

The same result is secured at Munich-Gladbach by a pipe which can be telescoped. At the upper end this has been enlarged like a funnel to secure a broad overflow and so avoid uneven disturbances.

At Cöpenick the emptying of earth tanks having a capacity of about 3,440,000 gallons (1300 cbm.), is accomplished every 3 to 4 weeks in 2 days by 8 pipes of 5.85 in. (15 cm.) clear diameter placed at different elevations. These lie in a wall 9 ft.

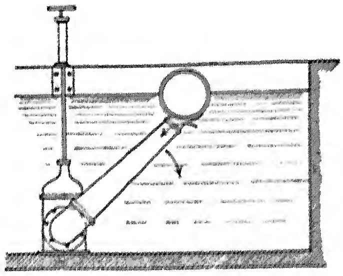


FIG. 3.—Floating arm for drawing off supernatant liquid.

10 in. (3 m.) long, which also serves as an overflow weir, and are closed by iron flap valves set at the ends on the water side at an angle of 45 degrees. These are closed by the pressure of the sewage and can be opened by chains from above. This simple device has proved very efficient.

All these arrangements, however, necessitate careful watching during operation. This is rendered unnecessary by the floating arm devices which were first used in England.

Here there is a circular or square pipe attached to a fixed horizontal one, which can be swung in a vertical plane (Fig. 3). The upper end is always kept 8 to 10 in. (20 to 25 cm.) below the surface of the sewage by one or two floats. Consequently the sewage is only drawn off from the top layer. At the same time the opening being submerged prevents floating substances,

such as scum and grease, from flowing off. The same purpose is sometimes served by a protecting box fastened between two floats (Fig. 4) or a floating scum board which cuts off a portion of the tank in which the floating arm is located and which moves in two grooves in the sides of the tank.

A valve is inserted in the horizontal pipe to regulate the discharge. In order to draw the sewage from the tank more evenly, the pipe leading to the valve may be divided into two branches which drop to each side of the tank (Fig. 4).

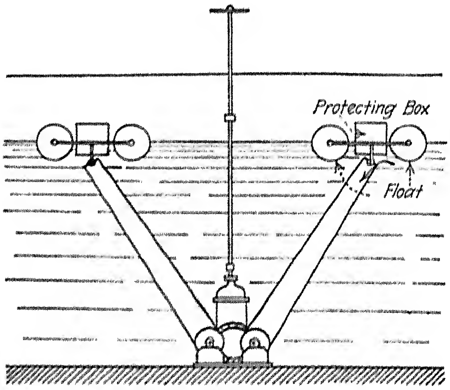


FIG. 4.—Double floating arm.

In employing a vacuum receiver for the removal of the turbid liquor the introduction of a well for this liquid is advisable, as this renders the effluent independent of the intermittent operation of the apparatus.

In wells where there is not room for such a floating arm, which must be longer owing to the greater depth, a hose may be used which can be lowered by a chain as the sewage is drawn down (Harburg), or the suction end of which is kept submerged by floats. In general there will be found no necessity for special devices in wells for the removal of the turbid liquor but the sludge pipes can be used for repairs and inspection purposes.

After the roily sewage has been removed the sludge must be drawn off. For this purpose a sludge sump should be provided in the tank, from which the pump draws off the sludge directly, or a sludge well should be inserted. The best position for the sump in tanks with the ordinary inclination is directly after the inlet, as most of the sludge is deposited here. In the experiments at

Cologne with a velocity of 1.56 in. (40 mm.) per second in the 11 ft. (3.35 m.) long sump (which is placed at the inlet just in front of the regulating device for securing a uniform distribution of flow), about 45 per cent. of the sludge was deposited, while in the remaining length of the tank—fully 130 ft. (40 m.)—only 55 per cent. was deposited. With a velocity of 0.78 in. (20 mm.) the proportion was 51 per cent. to 49 per cent., and with a velocity of 0.156 in. (4 mm.), 70.7 per cent. in the sludge sump and 29.3 at the bottom of the tank (Fig. 5). At the same time such a location of the sump prevents a silting-up of the cross-section and gives to the bottom of the tank an inclination toward the inlet favorable to effective sedimentation. On account of the opposing current of the sewage, however, the flow of the sludge is retarded

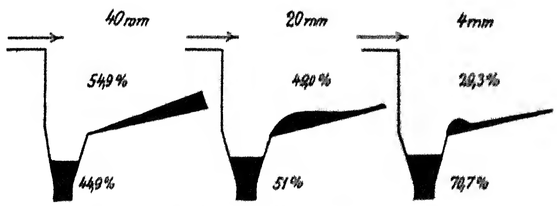


FIG. 5.—Deposition of grit in grit chambers.

While it was formerly thought to be advisable in constructing sedimentation tanks to place baffle walls and other impediments to the flow of the sewage in order to promote clarification, more recent methods aim rather at preventing detrimental currents and at removing the sludge as simply and economically as possible. For this reason the ground plan should be regular in shape and above all sharp angles and corners should be avoided from which it may be difficult to remove the sludge.

Earthen tanks are not advisable for thorough sedimentation, as they require frequent cleaning and, even for experimental plants a lining of cement or planks (which have been found serviceable in Bremen) should be employed. Otherwise the clarification tank must be used for sludge drying as well, as the muddy bottom would be removed with the liquid sludge. In drying sludge in tanks, too, it is well that the sub-soil should have some marked characteristic, such as a light color. Above all, it is impracticable to provide a tank with a natural bottom of sufficient slope to convey the sludge readily to the sump.

This mere detail is of particular value in tanks, for it is a disadvantage in this type of clarification chamber that the sludge must be removed separately from a large surface, and in cleaning by hand must be pushed to the sump by wooden or rubber covered scrapers. With the frequent cleaning necessary in sedimentation tanks this results in a great deal of labor and expense. It is, moreover, harmful to the workmen, who must often wade up to the knees in sludge and inhale the noxious gases from the decomposing material.

The attempt is therefore made to so construct the bottom of the tanks that the sludge, in pumping, will always flow by gravity to the pump well.

The slope in general use, say 1:100 (Mannheim and Cassel) to 1:45 (Hanover) is not sufficient, for experience has shown that some aid by manual labor cannot be dispensed with in these tanks.

For an easy, automatic flow with settled sludge containing at least 90 per cent. of water a slope of 1:10 to 1:15 is necessary, depending on whether there is much sand and coarse material, or whether there is a fine, fluid sludge. Such a steep slope is not feasible with tanks 130 ft. (40 m.) long. In some tanks a channel for the sludge has been built in the bottom, which gradually increases in depth and, for example, in Mannheim with an inclination of the bottom of 1:100, is given a fall of 1:50, in Munich-Gladbach one of 1:25. The attempt has been made, in addition to increasing the fall, to reduce the friction of the sludge in the deep channel relative to that spread out in a thin layer over the whole bottom. But even in this way it is not always possible to attain an automatic flow, as the inclination is still too small, and, moreover, on account of its fluidity, the sludge assumes a horizontal surface and does not flow from the sides into the channel and so into the sump, but spreads, rather, in a broad stream over the whole of the bottom. The channel, also, with its steep sides and curved invert, renders subsequent cleaning by hand more difficult.

To facilitate this, or, possibly, to install an arrangement for removing sludge which will be described further on, the tank should be built with a basket-shaped cross-section, or with straight lines and a steep diagonal slope, but without sharp edges or corners.

In Frankfort-on-the-Main, to entirely avoid subsequent clean-

ing by hand, two sludge sumps were constructed in a tank 135.8 ft. (41.4 m.) long, and the bottom had a longitudinal inclination of 1:10 toward these (Fig. 6). The diagonal slope at the ends and in the middle was 1:3, and near the sumps 1:2 (Fig. 7). These have a diameter of 8.2 ft. (2.5 m.). Their bottoms are conical with an inclination of 1:1. In addition, all surfaces exposed to the sewage are lined with glazed brick or, where this is not possible, as on small rounded angles, with smoothly dressed sandstone. In this way a perfectly automatic flow of sludge toward the sumps is secured. Moreover, a pipe for water under pressure with many connections has been laid, by the aid of which a thorough cleaning may be effected by jets, for the glazed surfaces gradually become coated with a sticky layer which increases the friction of the flowing sludge.

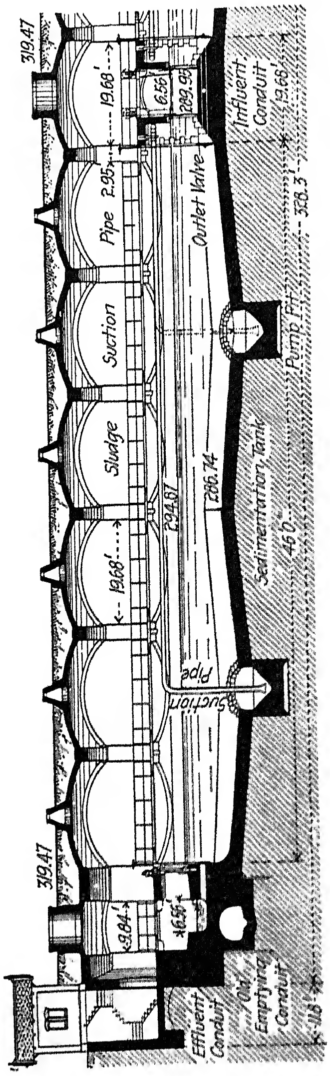


FIG. 6.—Longitudinal sections through the tanks.

Further attempts to divide the bottoms of tanks into separate hoppers facilitate the flow of the sludge and aid particularly in its removal during the operation of the plant and will therefore be treated of later.

In general every plant should be so constructed as to absolutely prevent any deposit of sludge in the receiving chambers, branching channels and entrance galleries by ensuring an ample velocity to the stream. We should endeavor to simplify the process by separating the sludge at as few places as possible

because, from the lack of suitable provisions, the removal of sludge from these parts of the plant can seldom be accomplished without interfering with the operation.

The next step is to effect the concentration of the sludge in the direction of the pump pit by mechanical means, and thus lower the cost.

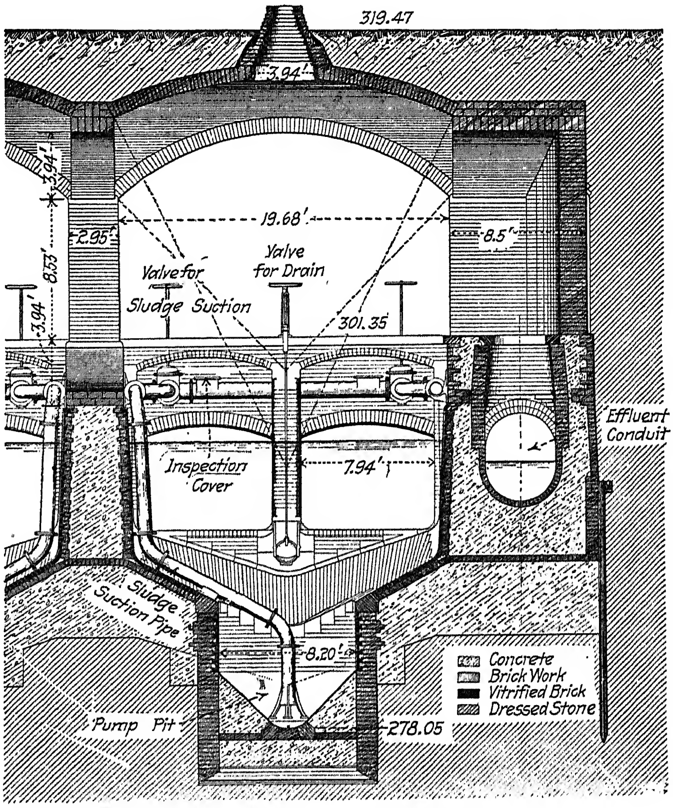


FIG. 7.—Development of cross-section of chamber with pump pit.

In the plant at Bremen a kind of wooden sludge car of simple construction is used (Fig. 8). This is about 14.8 ft. (4.5 m.) wide and runs by means of flanged iron wheels on substantial planks which project about 4 in. (10 cm.) above the wooden flooring with which the shallow tank at that place is provided. These shallow tanks, which are about 65.6 ft. (20 m.) wide, are therefore divided into 4 longitudinal strips corresponding to the

width of the car. The car has an adjustable squeegee on the forward side provided with a strip of rubber and is drawn by a rope from the effluent end to the sump at the inlet. The windlass is turned by the engine which operates the dredge, and as the rope runs over a guide-pulley it can be used for all four tanks. The return movement is accomplished by another wire rope which is drawn by a movable windlass operated by hand. This motion could have been effected by the engine already mentioned if the rope were led through guide pulleys around the tank, as

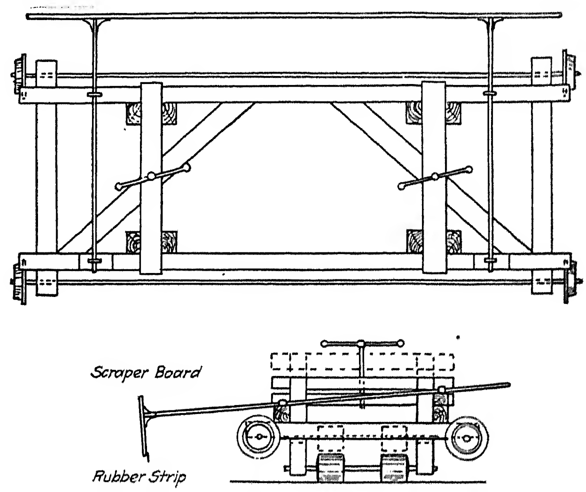


FIG. 8.—Car for removing sludge. (*Bremen.*)

customary with steam plows which are driven by one engine. To move the car across the end of the tank and for lifting across the wall separating two tanks, four wide rollers are used which can be inserted or removed by means of screws. Although where there is an accumulation of sludge, the car must make several trips, yet 78 to 92 cu. yds. (60 to 70 cbm.) of sludge can be removed from a large [commonly 32,300 sq. ft. (3000 sq. m.)] and nearly horizontal tank, by two men in one day, while formerly it required nine men for perhaps three days to do this. Moving the car across of course makes it necessary for the men to get into the tank, but this is only at the effluent end where there is little sludge and occupies but little time.

This has been avoided at Bolton by constructing in each of the shallow tanks, 328 ft. (100 m.) long, a sludge-pushing car (Fig. 9)

which, on account of the narrow width of the tank, serves for the whole cross-section. It is said that all the sludge in the tank can be removed in 15 minutes. It is doubtful, however, if the sludge can be removed by this apparatus without also drawing off the upper layer of sewage; for the watery sludge, on account of the slight difference between its specific gravity and that of the sewage in a full tank, would probably rise in front of the car and flow over it, aided by the current induced by the motion. This cannot happen with an empty tank on account of the density

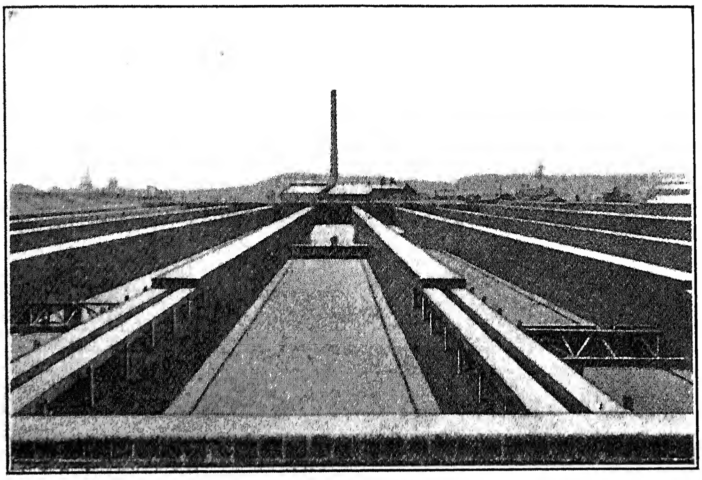


FIG. 9.—Ashton-apparatus for removing sludge from shallow tanks. (*Bolton.*)

of the sludge with its contained water. With a rounded cross-section of the tank such an apparatus, modeled after a canal-cleaning car, could be used and could be driven by a light movable windlass, preferably run by electricity. The whole construction could be made much simpler and lighter by having the rope attached to the squeegee at several points. The question of a gain in efficiency depends upon a uniform cross-section for the entire length of the tank.

b. Removal of Sludge During Operation

1. Construction

The somewhat costly and troublesome process of removing sludge during a suspension of the flow led early to the devising

of ways and means for simplifying and cheapening the work by continuous removal. Wells were first considered for this purpose, because the comparatively small sludge tank, especially in chemical precipitation, which was then in general use, with its large volume of sludge, required frequent cleaning; while its form offered the fewest difficulties to continuous removal.

Its principal advantage is in avoiding the costly removal of the turbid sewage, which in most places must be drawn off by pumps from tanks as well as from wells; and especially where the process necessitates frequent cleaning this is an important consideration. Moreover, the entire plant can be in use, while otherwise to avoid overloading it must be constructed of greater size in order to allow for those parts which lie idle during cleaning. It can be so designed, moreover, that only the dried sludge is exposed, provided closed pipes are used and the drying is done by a mechanical process described later on, so that the demands of hygiene are more completely met and foul odors are almost eliminated. But even if sludge is dried in the open air this method offers great advantages, especially if the places for drying are at some distance from the treatment plant.

A disadvantage in most plants cleaned during operation lies in the fact that their sludge contains a greater amount of water, not less than 95 per cent.

Where it can be utilized in this wet condition without further transportation or where ample areas for drying with favorable sub-soil and location are available, this matter is of less importance.

In those plants, on the other hand, where the drying or handling is done by machines whose size would have to be increased to correspond to the greater volume of sludge, one should consider whether the increased efficiency will pay for the greater outlay. As this manner of removing sludge always requires a material that will flow, it must often take place before it has fully settled. It is therefore especially adapted to thorough sedimentation, that is, where the clarified sewage is discharged to the stream without subsequent treatment and consequently must not be in a putrescent condition. The sludge shows an easily flowing consistency when it contains a small amount of grease, although it contains but little water. The Kremer apparatus is therefore particularly well adapted to the removal of sludge during operation, because we have with it the separation of the fats and cellu-

lose which are found in the partly clarified upper stratum of the liquid, while in the lower part we have the descending sediment.

It goes without saying that one can never predict with certainty regarding any of these details that all the sludge will be removed, and hence that there is no more putrescible matter present.

Removal of sludge during operation is effected either by the construction of the plant or by the introduction of some special mechanical device. Sometimes both of these means are employed.

A favorable concentration of the sludge at the bottom should be aimed at in the design. This end is most frequently attained

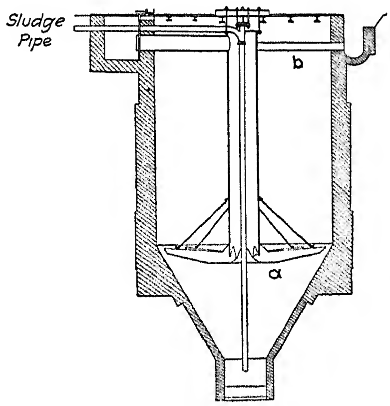


Fig. 10.—Dortmund tank.

with wells. As already mentioned, these are almost universally arranged for the removal of the sludge without preliminary emptying. With their comparatively small dimensions it is usually easy to give the bottom such an inclination that the sludge will flow by itself toward the suction pipe of the sludge pump at the center. A slope of 2 : 1, as is found in the so-called Dortmund tank (Fig. 10) and which is also used in England, suffices for all cases. A slope of less than 45 degrees, as in the sludge well constructed in the clarification tank at Frankfort, will permit a slippery sludge to slide off if submerged. The angles between the vertical walls and the conical base should receive especial attention, as experience indicates that the sedi-

ment in the sludge settles here. This can be prevented to a certain extent by rounding these corners.

Naturally, the degree of roughness of the bottom helps determine the slope. In large plants it is well to make experiments with the sludge which comes from the sewage to be treated, unless the slopes have been determined by reliable experiments with different kinds of sludge on different surfaces from which it slips off by its own weight.

It should furthermore be noted that in course of time a sticky coating is deposited on the smooth surfaces, reducing their efficiency very considerably—especially in the case of smooth enameled or glazed surfaces and those of glass—and that their cleaning necessitates a cessation of operation.

The cone formed at the bottom of the wells corresponding to the natural slope of the earth will not suffice for a free removal of the sludge.

It has been shown by experiments of Schoenfelder at Elberfeld that a steeper slope is required to secure an automatic sliding of the sludge if removed under water than if the supernatant liquid is first drawn off, and that special precautions should be taken in the process. Here it was observed that the sludge was deposited in horizontal layers not of uniform thickness, parallel to the bottom. When the sludge was drawn off at the deepest point a funnel was formed. After this the sludge failed to slide, although having a slope of 1:3; but this did occur immediately after drawing off the supernatant sewage. The explanation of this is that the difference in weight between the saturated sludge and the turbid sewage above is too slight to overcome the friction of the surface at the bottom and of the surface in contact with the turbid sewage; for the weight of the sludge is reduced by that of the displaced sewage, while in the case of empty tanks the weight of the sludge becomes effective. The funnel mentioned gradually closed in again under water so that in a half hour it was always smooth and horizontal.

This was confirmed by experiments at Cologne. Here the sludge was to be pumped from under water out of sumps having a slope of 1:1. It soon appeared that after a few minutes only water came out, which found its way through the compact sludge near the suction strainer and carried with it only a few fragments of sludge which it was able to dislodge. This, which is also confirmed by practice and experiments elsewhere, proves

that the removal of sludge under water and without stirring up the deposited material is only practicable before the sludge is firmly settled in place. The composition of the sludge is of importance in this connection as the greasy material forms a light but firm mass, while sludge from septic tanks which is kept in motion by frequent partial removal, as in the Emscher tank, and, by the gases rising from it, can easily be removed during operation.

In these plants, which, as is known, are a combination of short sedimentation tanks, with septic chambers below, the difference in quality between the fresh and septic sludge is taken into account by giving the floor of the upper part a slope of 1 1/2 : 1, and in the most recent structures this is covered with glass plates laid on reinforced concrete supports to lessen the friction. Such precautions are necessary in order to induce the settled sludge to slide down in thin layers to the lower chamber as soon as possible.

As the experiments of Grimm (which led him to introduce sedimentation plates in the tanks) have shown, this is promoted by the fact that colloidal matter has a marked tendency to form a gelatinous coating by friction, or even by contact, with a solid body. This is then set in motion on the steep surface by gravity, and in rolling down carries with it the particles of sludge which are in the way. In order to convey the septic sludge, which fills the lower tank in a great mass, to the sludge pipe a slope of 1:2 is sufficient, to which may be added a flushing pipe to be described later.

The many other forms of wells which have been constructed in view of the particular end to be reached, and especially for chemical precipitation in all its different phases, more particularly with reference to the introduction and distribution of the sewage, are subject to the same principles regarding the removal of sludge as the Dortmund tank, given as an example. The same is true of the short, shallow tanks, having the base constructed as a pyramid, with sides sloping at 45 degrees or more in order to facilitate the removal of sludge. The advantage of this form is made evident by the simplicity with which the desired purpose is effected.

The attempt has also been made in various ways to remove the sludge from the ordinary long shallow tank while in use.

In Thorn the bottom of a tank fully 65.6 ft. (20 m.) long and

perhaps 26.2 ft. (8 m.) wide, having sides with a slope of less than 45 degrees was divided for this purpose into 4 parts (Fig. 11)[1] by constructing saddle-shaped division walls, from the lowest point of which the sludge was led under water pressure to the sludge channel which was used in common for two tanks.

A similar solution by the use of hopper-shaped bottoms has been employed by Schoenfelder at Elberfeld (Fig. 12), but their

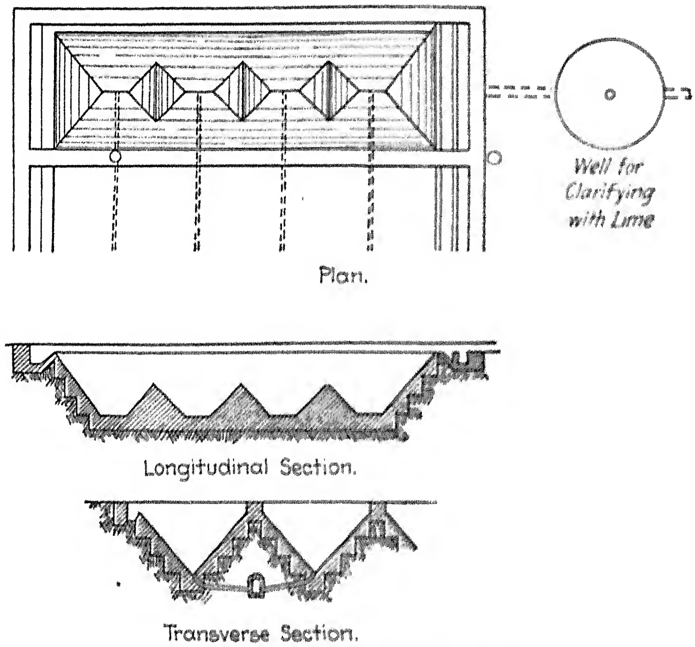


FIG. 11.—Sedimentation tanks at Thorn.

dimensions have been made quite different for the following reasons: As the largest amount of sludge settles in the first quarter of the tank, as was observed in the Cologne experiments, the last hopper-shaped compartments, if the tank were composed of compartments of equal size, would require very much longer to fill with the fine sludge than the first ones in which the coarser constituents were settled out. In this way a separation of the sludge according to its composition was effected. This is particularly valuable because the fine sludge, on account of the

[1] Fig. 11 is taken from Salomon's "Die Stadtische Abwasserbeseitigung in Deutschland," 1907.

light weight of particles of fat, contains the most grease and can later be manipulated so as to separate this out, while the coarse sludge, on account of the small amount of grease, can be drained more quickly and easily. For this reason the sludge tank at Elberfeld is divided for the purpose of receiving these two kinds of sludge, without, however, any use being made of the device as yet. Another advantage is that the hoppers for the fine sludge can have less slope, on account of its greater fluidity, at least in the upper portion, besides being of smaller dimensions. Experiments with a model demonstrated that less slope was required for the concentration of the sludge under water, while a steeper one was required to avoid the formation of funnels while forcing it out. Therefore steeper hoppers were inserted to ensure a removal of the sludge.

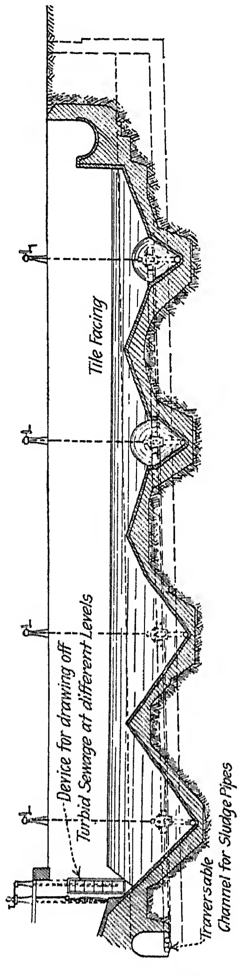


FIG 12.—Device for drawing off turbid sewage at different levels.

The easiest way to measure the height of the sludge in wells and tanks is by lowering a sheet iron plate attached in a horizontal position to a measuring chain. By the increased resistance to the vertical movement of such a plate in sludge in comparison with water one can determine with sufficient exactness the height of the sludge by reading from the chain.

It is not sufficient to concentrate the sludge at one or more points under the sewage, but it must also be delivered, and herein lies a particular difficulty in the removal of sludge during operation.

The delivery of the sludge can be accomplished 1. by suction with pumps, vacuum receivers or similar apparatus in the same way as in its removal during suspension of operation; 2. by drawing it off by the aid of hydrostatic pressure, either toward a deeper channel or sludge well or, under pressure, through a rising main, so that it is dis-

charged but a little below the level of the surface of the sewage in the well or tank.

The insertion of a sludge well in making use of vacuum apparatus is of advantage, as in this way a uniform flow of the sludge is procured and fluctuations of the flow resulting in the entrainment of larger amounts of water, as may readily occur by the intermittent operation of such an arrangement, may be avoided. Moreover, this permits observation of the amount of water contained in the sludge delivered from plants to which it is adapted; which is otherwise only possible at the end of the rising main, and as this is often at some distance from the clarification plant, it is impracticable.

In forcing sludge through a rising main there should be a difference in elevation of 2.6 to 3.3 ft. (0.8 to 1.0 m.) between the surface of the sewage and the discharge end of the pipe with ordinary settled sludge. With the Emscher tank this should be increased to 5.0 ft. (1.5 m.). Here two flushing pipes are provided for water under pressure of which one, forming a ring, is perhaps at the elevation of the connection between the cylinder and the conical base, and, with its orifices directed downward, is intended to assist the sludge in sliding down the gentle slope of the base. The second terminates opposite the entrance to the sludge pipe in a loop with three orifices directed toward the center. This serves as a supplementary aid and to start the flow in case large masses of grit should collect there. As a failure of such plants is usually through refusal of the sludge which has accumulated in the pipes during a cessation of operation to flow after opening the valve, it is advisable to provide the sludge pipe with a branch pipe from the water main, as has been done with the Emscher tanks, so that the pipe may be filled with water after each emptying of sludge and the remaining sludge forced back to the tank. By means of these pipes positive action can be secured under difficult conditions, as the author can testify. The use of the two last-mentioned pipes is always well where there is difficulty in forcing out the sludge, especially in large plants where there is almost always water under pressure available for flushing purposes. The sludge pipe should always be as straight as possible, avoiding sharp curves, which cause a loss of pressure.

In conveying sludge under pressure where the operation is not continuous, care should be taken, in starting its movements, to

avoid the formation of the funnels already mentioned. For although the water exerts a uniform pressure on the nearly horizontal surface, the vertical column of sewage over the pipe entrance will be set in motion by the sudden opening of the valves and will then settle and so increase the height of the column above. This, with the friction of the masses of sludge on the bottom and sides, helps in the formation of a funnel.

This can be effectively prevented by a device called a sludge cylinder (German Patent) of the Company for Sewage Purification (Berlin-Schoeneberg), which can be attached to their

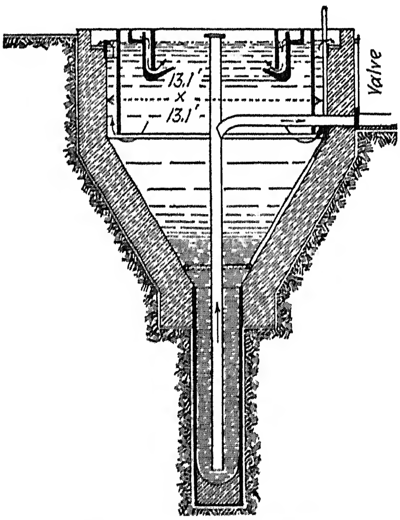


FIG. 13.—Kremer apparatus.

Kremer apparatus (Charlottenburg) (Fig. 13). The bottom of the tank converges to a hopper having an inclination of less than 60 degrees with the horizontal, and is continued as a cylinder 2 ft. 7 1/2 in. (0.8 m.) in diameter, in which the sludge is collected. The sludge pipe ends at the bottom of this cylinder, and through this the sludge is removed by hydrostatic pressure. The formation of funnels with the resulting discharge of sewage is not possible in the narrow cylinder, so the sludge, which contains comparatively little water in the Kremer apparatus (80 to 85 per cent.) is removed from the tank without change in its favorable composition.

2. Mechanical Contrivances for Removing Sludge During Operation

These mechanical devices may be classified as follows:

1. Those which, by stirring, mix the required amount of water with sludge that is not adapted to continuous removal, or at least assist in initiating its movement.

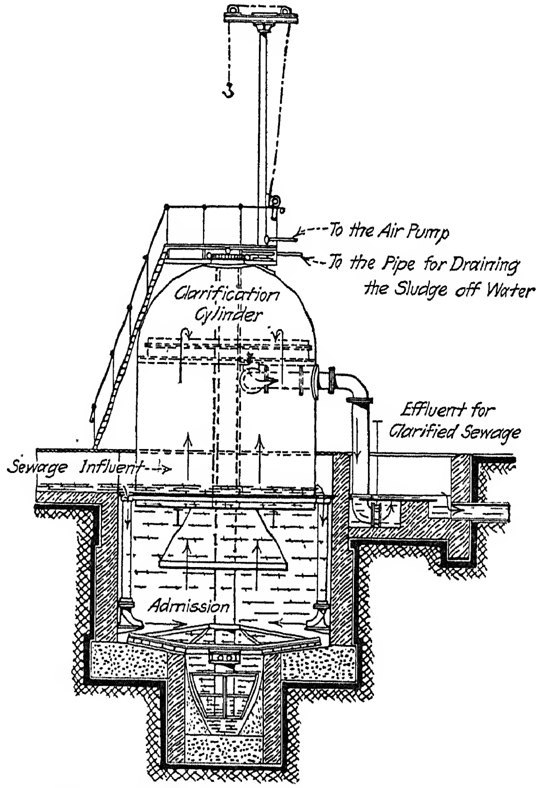


Fig. 14.—Stirring device and skimmer in sedimentation tower in the lignite process.

2. Those which collect the sludge at certain points, from which it may be readily conveyed.

3. Those which, without materially affecting its settling, draw the sludge off from the place where it has been deposited.

The stirring devices of the first category act in opposition to the principle laid down at the beginning of the section, that the

consistency of sludge should not be detrimentally altered in removal, and are therefore to be avoided as much as possible. They are sometimes installed later if the sludge does not flow of itself on account of too flat a slope in the bottom. If removal takes place during suspension of operation, the height of the stirring device above the bottom should be adjustable from above, so as to be always in contact with the top layer. (Wells at Mairich, Neustadt O.-S.). The chief occasion for their use is in the towers used in lignite treatment, as stirrers can only be used in wells or towers. They are commonly provided with a device for maintaining a light contact with the sludge surface and are kept continuously in slow motion (Fig. 14). The flush-

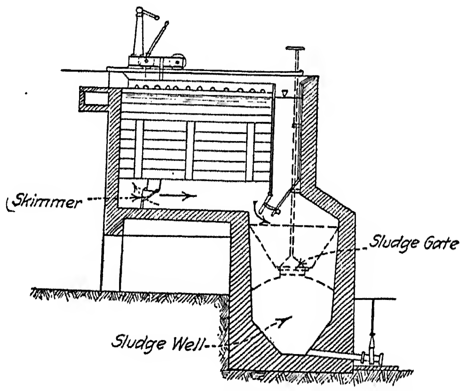


FIG. 15.—Skimming apparatus and sludge tank in the Kremer apparatus.

ing pipes with water under pressure, already mentioned, as well as arrangements for securing the flow of sludge by compressed air, should be included here. Stirring the sludge is said to promote its digestion in Emscher tanks, but disturbs uniform settling in sedimentation tanks.

Arrangements for concentrating sludge are based upon the same idea as the apparatus described for use during suspended operation, but the construction may be lighter as the volumes of sludge to be disposed of on account of more frequent removal are smaller and do not offer so much resistance. In an experimental Kremer apparatus at Charlottenburg a simple surface scraping apparatus was found serviceable in a square tank with a flat bottom. The apparatus (Fig. 15) consists of a scraper in the shape of a board which can be turned on its upper edge

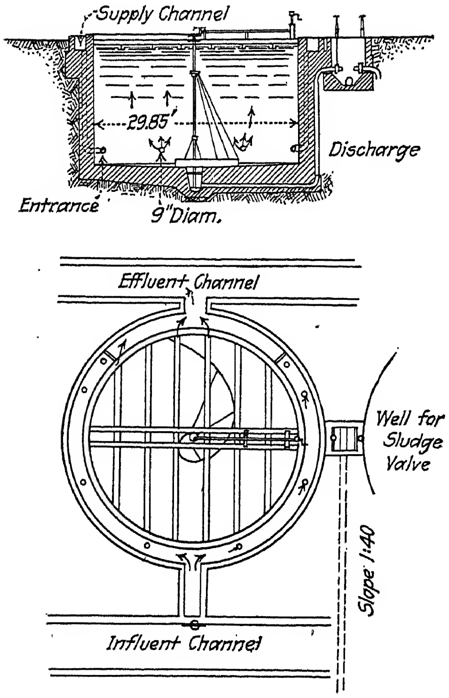


FIG. 16.—Spiral shaped sludge collector. (*Fidler Patent.*)

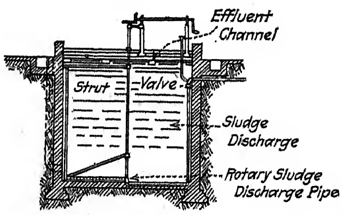


FIG. 17.—Sedimentation tank (Candy system) with rotary sludge discharge pipe.

during its reverse motion. This scraper is operated by two vertical rods which are attached to a small four-wheeled car running on rails placed over the upper edges of the tank and moved by hand.

The scraper in the stirring device of the lignite process towers operates in the same way, and for wells having a very steep base a scraper composed of a vertical scraping board which forces down the particles of sludge adhering to the walls may be found useful. The motion, which can be transmitted by gearing, should be very slow in this, as in the following apparatus, to avoid the formation of detrimental currents.

The patent sludge collector of Fidler works by collecting the sludge by a rotary motion and can be installed in wells having a flat bottom. It is also used at Bolton in a long rectangular tank, where several such appliances are placed side by side. On account of the dead corners some supplementary hand labor is required, however. As shown in Fig. 16, the sludge gatherer consists of a spiral-shaped iron band which is set in motion by a hand-operated gear and which sweeps the sludge to the center, from which it is drawn off by suction or forced out, as illustrated in the cut. Twelve large wells on this system have recently been installed at Bury.

The arrangement in the third category consists of a perforated pipe laid close to the bottom and connected with the sludge pipe and into which the sludge is forced by the pressure of the water. A rubber squeegee can be attached to this pipe which scrapes the sludge from the bottom. Fig. 17 shows such a pipe in a well of the Candy system. This is also connected with a wall scraper. Motion is derived from a gear-wheel operated by hand. The same principle applied to a shallow tank is shown in Fig. 18, representing a plant in Heywood. The perforated pipe is guided here by two rack rails into which the pinions conveying the motion engage. The sludge is here raised up by a siphon over the side wall and into a channel which is common to two tanks. A pressure of 3 ft. (0.90 m.) is sufficient. The siphon is started by cutting out the upper part by the valves *a* and *b* which is then charged with a pump operated from the same platform as the moving machinery. The horizontal suction pipe is provided with a rubber squeegee. A disadvantage in this form is that important moving parts of the machine are submerged.

These contrivances for removing sludge require for reliable

operation a liquid, easily flowing sludge and must therefore be cleaned out every day, or at least every two days. The sludge obtained contains about 97 per cent. of moisture, as the turbid sewage finds its way to the entrance more readily than the sludge is drawn off from the bottom. With a pipe which rotates about a central axis it follows that the motion is slower near the center of the tank, while the friction is reduced on account of the short length of the pipe; therefore more sewage is taken in here. As this sludge, with 97 per cent. of moisture, has twice the volume of that with 94 to 95 per cent. in the Dortmund tank when in operation, with the same amount of dried matter, the use of this method of collecting sludge is seldom to be recommended. Besides, with a larger proportion of mineral matter, as often

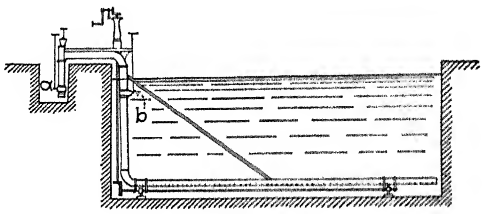


FIG. 18.—Movable sludge discharge pipe for sedimentation tanks.

occurs after a thunder storm, the operation is more difficult and uncertain. In the Fidler system this is not the case. As sludge containing less water is secured here, while its delivery remains the same, this should have the decided preference.

While the aim of all these structural or mechanical arrangements for removing sludge during operation is to collect the material in clarification tanks, or at least to draw it from these directly, there are some which enclose it in a special chamber or compartment without removal of the supernatant sewage, the intention being to prevent subsequent admission of the turbid sewage and its mixture with the sludge and to secure the latter as free as possible from moisture.

It is well to consider here the introduction of a partition wall with a valve (sluice gate) leading into the sludge chamber which has been found valuable in the Kremer apparatus at Charlottenburg (Fig. 15) and has also been used in similar plants by the Sewage Purification Company. This permits a discharge of the accumulated sludge with no fear that the turbid sewage will pass

out with it. The sludge can be drawn off from here, in which case a pipe for the admission of air should be inserted from the sludge tank to above the surface of the sewage, or it may be forced out by the introduction of compressed air.

Grimm (*Gesundheits Ingenieur*, 1909) attempts to apply the foregoing principle to shallow tanks in a somewhat different way. The bottom is divided into hoppers 10.76 sq. ft. (1 sq. m.) in area with side slopes of 45 degrees, from whose lower points vertical pipes lead, each row of which is connected by a transverse pipe (Fig. 19). The sludge slides into these pipes, which have a diameter of 3.9 to 5.9 in. (10 to 15 cm.) and may increase in size at the bottom, and its separation is facilitated by hoods or plates, according to Travis' theory, through which the water is

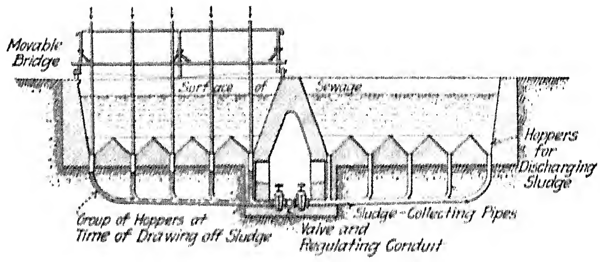


FIG. 19.

forced out. The height of the accumulated sludge can be observed for each transverse row of hoppers in a glass stand pipe connected with the sludge pipe at the traverseable sludge passage-way.[1] When the depth is sufficient, the tops of these sludge pipes are closed by plugs carrying an air pipe reaching above the surface of the sewage and rendered accessible by a movable foot bridge. When the valve of the sludge pipe at the passage-way is opened, the sludge is discharged by gravity or suction, while air enters by means of the aforesaid air pipes through the plug valves. When the sludge is drawn out and the gate valve closed the pipes will fill again with turbid sewage by opening the plug valves and are then ready to receive sludge once more. By this arrangement, if the plug valves are tight enough, the subsequent entrance of turbid sewage is prevented; that is, a dry sludge is secured by allowing it to accumulate in a thick layer. By providing a steep slope in the cross pipes the

[1] In the division wall between the tanks. Trans.

flow will be facilitated. In order to realize all advantages, however, this plant requires conscientious superintendence.

A company for the purification of water and sewage at Neustadt a. d. H. has a patented device called a sewage preparer which prevents the sludge, that has accumulated in the sludge channel of a short tank having steep slopes on each side, from passing through the tank with the current, by a series of horizontal shutters operated from above. This is said to reduce the friction in continuous treatment and facilitate sliding. If the shutters are laid flat they shut off the sludge channel on the side of the tank, leaving an entrance only at the upper end. By opening the gate valve sludge will be forced out of the channel by the pressure of the sewage above, as though from a tube. It is doubtful, however, whether the shutters in the lower part of the sludge-filled tank can be closed tightly enough to prevent the turbid sewage from mixing with the sludge in large quantities, especially in the neighborhood of the outlet, as the moving parts are mainly under water and cannot be constantly watched.

c. Contrivances and Conduits for Conveying Sludge

Various contrivances have been employed to remove the grit from clarification tanks in case the sludge cannot be forced out by the pressure of the sewage above. These are:

1. Dredges.
2. Pumps.
3. Vacuum apparatus.
4. Various other contrivances.

1. As already remarked, dredges are chiefly used to clean out grit chambers. The transport of the material in large plants is often accomplished by belt conveyors.

Dredges should not be used to remove sludge from clarification tanks, especially during operation, as a thorough cleaning with them is not possible. It is also better to use other contrivances in sludge wells, on account of the dirtiness of the operation.

2. In using piston pumps the great difficulty encountered is to keep them water-tight, as they soon become worn out by the sand brought in. The valves, also, often interrupt operation and should therefore be placed where they are readily accessible. Hence it is an advantage to have a good grit chamber for the protection of the pumps. It is also to be noticed that in very

sandy sludge the suction lift is reduced, so that pumps and vacuum apparatus must be placed lower. Coarse bar screens are also necessary with all kinds of pumps, to prevent pieces of wood or other coarse material from injuring the pumps. If these coarse screens are placed in the tank in front of the sludge channel or sump, as at Mannheim or Munich-Gladbach, the amount of the screenings will be less, because much of it, especially lumps of fecal matter, disintegrate in the tank; but their removal from the bottom is less cleanly and more troublesome. It is advisable to install a sludge well where the sludge is not removed during continuous treatment, as the pumping plant may then be made smaller without increasing the time of removal. With a very viscous sludge it is of advantage to have a stirring device operated in connection with the pump.

Diaphragm pumps, such as those furnished by Bopp and Reuther of Mannheim for the clarification plant at Hanover, are superior to ordinary piston pumps and are also much used elsewhere. Here the piston works in clean water, which conveys the pressure through diaphragms to the sludge which is to be delivered.

Centrifugal pumps are also well adapted to the transport of sludge, but it is important that the impellor should be accessible. With sandy sludge there is a great amount of wear on the packing rings. They are particularly serviceable in pumping roily water because of their simple design, especially when operated by electricity. By means of connecting pipes they can also be used for reserve power in pumping sludge.

For small plants and as a reserve in those where sludge is propelled by hydrostatic pressure, the well-known diaphragm pumps are very useful.

3. With a vacuum apparatus it is well to connect two receivers, so that the air drawn from one will serve to force the sludge from the other, which was previously filled. The air pump must therefore be arranged to act as a vacuum and force pump. The operation of the valves is then automatic. To prevent the sludge from running into the air pump a U-shaped pipe should be inserted between it and the receiver, the top of which should be at least 33 ft. (10 m.) above the highest level of the sludge. Vacuum receivers are especially necessary where, from absence of grit chambers and screens, much coarse material is mixed with the sludge. They may also be used to propel the sludge for

long distances. In Oppeln the sludge is forced 3600 ft. (1100 m.) in a pipe 12 in. (300 mm.) in diameter. They, however, occupy more space than pumps.

The patent Wegner vacuum wagon works on the same principle as the vacuum receiver. Here, in a portable receiver which can be used to transport the sludge, the air is rarified by exploding benzine, causing the sludge to be sucked in. This apparatus is especially recommended for use with very small plants where, because of the proximity to improved property or public works, it is desirable to have an odorless removal of the sludge without the necessity of constructing a special plant for pumping it. As the receiver can be brought to any tank or well, the cost of sludge pipes is saved. The removal is also odorless. This mode of operation has been found very satisfactory at Merseburg. In some cases the pneumatic apparatus used for cesspool cleaning can be used in the same way.

4. The steam ejector, among other contrivances, should be mentioned next. This has not been found useful in cleaning grit chambers on account of the consistency of the detritus. This difficulty might not hold in the case of the liquid sludge from tanks, but the disadvantage of the large consumption of steam outweighs the advantage due to its simple construction and the small amount of room taken up. In sewerage systems in which the sewage is lifted by compressed air their use may be considered.

In the recently installed plant at Siegen an effort was made to convey the detritus of the grit chamber which lies at a high elevation, by means of a horizontal spiral screw delivering into a tip car at the outlet end, without interrupting operation of the plant, but as yet without success.

Sludge pipes should always be accessible on account of the liability to stoppage, and should, therefore, not be enclosed in masonry for any great length. It should, moreover, be possible to produce a strong scouring current by water pressure or by the aid of sludge-propelling devices. Sometimes an open traversable channel between the tanks, in which the pipes are laid (Elberfeld) or into which the short sludge pipes open from the side (Mairich plant at Guben and Ohrdruf), serves as a sludge channel. This has the advantage, where sludge is removed during operation, that one can see the amount of water removed as soon as it comes out and act accordingly. The advantage of the possibility

of using a pipe which opens into the sludge-well as a siphon to produce suction is, however, lost.

The open channels to convey the sludge to the drying beds, which are intended to be used in the day time, should have the maximum hydraulic radius in order to reduce the friction.

The inclination which should be given pipes and channels to secure a flow of sludge without assistance depends upon its nature and should not be too light. Very liquid sludge, with about 95 per cent. of water and but little sand, may under some circumstances be given a slope of 1:100, but 1:80 is better. For sludge obtained with interrupted operation a fall of 1:40 to 1:50 is necessary. The plants of the Emscher Association have grades of 1:20 to 1:40, while the pipe conduits at Elberfeld have 1:30.

Enclosed pipes are always preferable to open channels for hygienic reasons, especially for long distances. Moreover, the sludge is more readily moved and deposits of sludge can be more easily flushed out.

The valves in the sludge pipes should be strong and simple. Those which have a bearing on one side only should have the operating screw on the outer side engaging in a rack on one side only. Valves in pipes should be designed without a bottom groove, and should bear on the narrow edges of the disc in order to prevent an accumulation of coarse material which would prevent the valve from closing.

CHAPTER IV

REDUCTION OF THE WATER IN SLUDGE

The large amount of water in sludge is a drawback to its use in any way and reduces its value on account of the work involved in its reduction. If it is used while wet the valueless water it contains limits the area to which it can be applied, on account of the increased cost of transportation. Moreover, this liquid condition adds to the difficulty of transportation, as this can only be accomplished in water-tight vessels, and temporary storage in the field is impracticable without much preparation and apparatus.

With perhaps 75 per cent. of moisture it can be loaded with a shovel and does not require a perfectly water-tight vessel. With 60 per cent. of moisture it is quite firm and resembles damp garden mould. It should therefore be reduced to this condition.

Fig. 20 shows at a glance the relation between the amount of water removed and the consequent reduction of volume. The curves represent sludge of different degrees of original moisture, volumes in per cent. of that from which the water has not been extracted being represented by ordinates, while the abscissas represent the degree of de-watering in percentage of moisture contained in the whole. The horizontal line limits the volume of the dried residue, which remains constant. The distance of the curve from this line gives the amount of water contained in the sludge.

It can be seen here how much water should be removed to reduce the amount in a wet sludge by 10 per cent. and how the quantity of water necessary to reduce the moisture to a given percentage rapidly diminishes. For example, from 100 lbs. of sludge containing 90 per cent. of water (Fig. 20) 50 lbs. of water must be removed to reduce it to 80 per cent., while reducing the same original volume from 60 to 50 per cent. requires the removal of but 5 lbs., and from 30 to 20 per cent. only 1.8 lbs.

A comparison of the different curves shows by the steep slope on the right hand side—that is, at the commencement of de-

watering—how important it is for subsequent drying and treatment in general to have the sludge as dry as possible from the beginning; for the increase in the water content of the sludge corresponding to an increase of, say, 5 per cent. of moisture, has a varied effect, according, as we obtain a sludge containing 80 per cent. instead of 75 per cent. or sludge of 95 per cent. instead of 90 per cent. moisture. This is also of importance in considering the arrangements for treating the sludge described in the last section.

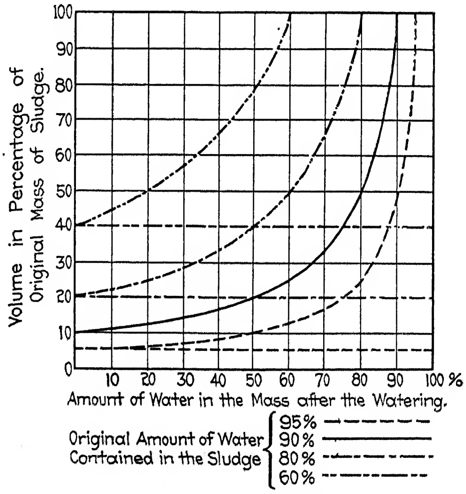


FIG. 20.—Reduction of volume in sludge with extraction of water.

On the other hand, it is recognized that drying beyond 50 per cent., at least with the very wet sludge from tanks, has but a slight effect on the reduction of volume, and for this reason alone further de-watering is not warranted.

For example, sludge originally containing 95 per cent. of water has, when dried to 60 per cent., but 1/8 of the original volume, and so the cost of transportation is correspondingly lessened, and the extent of its use as a fertilizer is increased, as the amount of dried material, which alone is of value, remains unaltered.

The following requirements should be observed in the process of de-watering:

1. The drying should not involve too great an expense, so that the expected increase in value of the product is not lessened. This may be accomplished by removing the water, by incinera-

tion, for instance, thus facilitating its transportation and a more rational utilization.

2. It should be effected rapidly, especially when done at the plant or in the neighborhood of habitations, in order to avoid accumulations of filth.

3. The operation should produce no nuisance in the neighborhood from foul odors or otherwise.

4. Handling of the sludge by workmen should be avoided, for reasons already stated.

The methods of removing the water are as follows:

a. Drying in the air.

b. Drying by filter presser.

c. Drying by centrifugal machines.

d. Other methods of reducing the moisture.

a. Drying in the Air

Drying in the air is the process most commonly employed, especially with small plants. For this purpose the sludge is conducted into shallow basins. These are surrounded by earthen embankments or, less frequently, by slope paving, wooden sides or solid walls. The drying is effected in part by evaporation of the water and partly by its drainage into the underlying soil.

If this is porous, subdrainage at a depth of about 2.3 ft. (0.7 m.) with a small distance between the separate lines of pipe is sufficient. Sometimes even this is unnecessary. In some cases, however, an artificial construction of the bottom, similar to a filter, is necessary, as with the natural subsoil the accumulation of sludge increases, so that it becomes necessary to remove and renew it. The depth of such a filter is usually 15 to 24 in. (40 to 60 cm.). The drainage channels, about 4 to 6 in. (10 to 15 cm.) wide, are laid with open joints at a distance of from 4 to 10 ft. (1.2 to 3.0 m.) apart and are covered to a depth of 12 to 16 in. (30 to 40 cm.) with cinders from boilers, pebbles or coarse gravel. A thick covering of fine cinders or screened gravel [2 to 4 in. (5 to 10 mm.) in size] follows this, 4 to 6 in. (10 to 15 cm.) in depth. This layer is to prevent the sludge from penetrating further into the filter. As the topmost layer becomes choked with sludge and portions of it are carried off with the dried sludge, it has to be renewed from time to time. To prevent this the bed may be covered with heavy stone paving, or, as at Leipzig, with

a layer of bricks. The joints are then merely filled with sand. As all the water drains through these comparatively narrow spaces they soon become clogged with sludge, and the entire pavement must be taken up and renewed.

The liquid drained off, which is usually somewhat turbid, owing to particles of sludge, and also putrescible, may be led to the intake of the clarification plant and treated again. As the volume is comparatively small, it does not alter to any great extent the sewage to be treated. In many cases this is impossible without long conduits or even devices for lifting it, especially where the sludge is removed by hydrostatic pressure and brought by gravity in open conduits to the drying bed. In this case a small supplementary tank for subsequent sedimentation or a filter (Elberfeld) for the sludge liquor is advisable. If the sewage is subjected to subsequent purification by contact beds or sprinkling filters the sludge liquor can receive further treatment there.

The liquor from drying beds after septic treatment requires no further treatment and may be led directly to the outfall, being odorless, clear and nonputrescible, as shown by the plants of the Emscher Association. By this method most of the water separates out in the first 12 hours and the sludge floats on account of the expansion of the contained gases, while a layer of clear water is formed underneath. The water should be drained through the filter as quickly as possible, for after the gas has been given off, at the end of 15 or 20 hours, the sludge sinks, due to its specific gravity, and the water rises over it. The same phenomenon is observed in the deep sludge pit at Leipzig, except that here the water is not drained off from below, but is allowed to evaporate after it has risen above the sludge.

With very greasy sludge it is sometimes impossible to draw off the water at the bottom, as at Frankfort-on-the-Main and Mannheim, as the particles of settled sludge form an impenetrable layer. The small amount of water on top can then only be drained off in as many places as possible through openings in the surrounding walls, which can be closed.

If fresh sludge is discharged on top of beds of partly dried sludge, as can scarcely be avoided where the sludge is seldom cleaned out, it will dry more slowly on account of the heavier liquid beneath. The boundaries of the basins can be wholly or partially made of a sort of woven brush-work, thus obtaining a

lateral removal of the water through these boundaries (Elberfeld, Halberstadt). Nevertheless, the efficacy of this mode of draining the sludge is greatly diminished by the fact that the rapid delivery of the water through the brush and the influence of the air in drying the accumulation of deposited matter at the sides soon make a nearly impervious layer, because the moisture does not come rapidly enough from the interior. At Halberstadt, therefore, it is not considered advisable to retain this device.

At Bremen the basins were subdivided for this purpose by perforated planks, between which narrow passages were left for drawing off the liquid that leaked through and for removing the

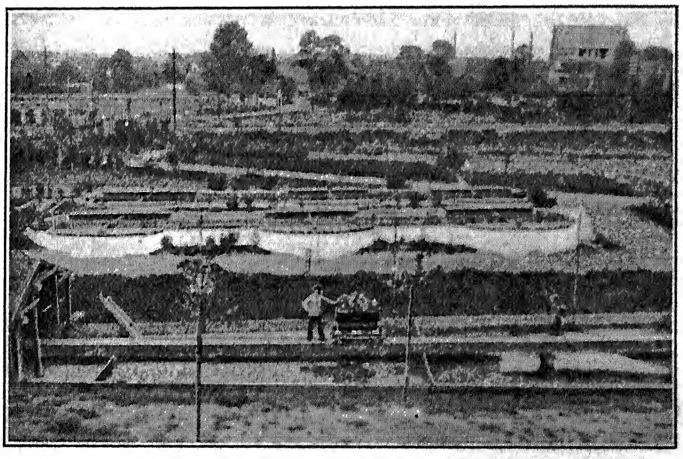


Fig. 21.—Sludge beds of the Recklinghausen Clarification Plant.

dried sludge; but this device was removed because the sludge found its way through the holes, making its handling more uncleanly, without resulting in a more rapid drying.

If this is to be accomplished the sludge should be brought into the basin in thin layers, 6 to 10 in. (15 to 25 cm.) in thickness, and the basin should be filled as rapidly as possible, in order that the free removal of the water at the bottom may not be made more difficult by sludge which has had its moisture drained off. Small, shallow tanks are therefore to be preferred. These can be economically provided in small installations by constructing a border of planks placed on edge. In this way the excess area required by earthen embankments is utilized. (See Fig. 21.)

In the cut, which shows the plant of the Emscher Association at Recklinghausen, the sludge running into an empty compartment may be plainly seen on the right. The sludge is forced out by hydrostatic pressure from 6 Emscher tanks lying beyond. In order to maintain a uniform depth of the layers the bottom should be made horizontal, as the sludge, due to its fluid nature, assumes a horizontal position.

A disadvantage of plants with small, shallow basins lies in the greater cost of removing the dried sludge, as this comes in thin layers and necessitates frequent re-location of the rails for transportation, unless these are laid on an elevated trestle, as at Recklinghausen. This is obviated by the use of wheelbarrows.

In selecting a location for the drying beds care should be taken that, with a porous soil, there are no wells in the vicinity that can be contaminated by infiltration.

Especial care should also be taken with reference to odors and the plague of flies. These nuisances have again and again led to attempts to replace the cheap method of drying in the air by others, even though more expensive.

As partial decomposition accompanies the operation of drying the foul odors caused by gases arising from the sludge, especially in the summer, give much discomfort to persons working or living near the plant. It may even result in lowering the value of land in the vicinity and cause great expense for indemnification. Likewise the plague of flies is very troublesome in the neighborhood, as the fermenting sludge offers an admirable breeding place for all kinds of flies and gnats.

An attempt has been made to prevent this nuisance by adding some substance to the sludge. Such substances are either intended to stop putrefaction or else to form a cover to the sludge.

In Cassel, for example, as well as in other places, lime has been successfully added to the sludge in the basins and at the outlet in the proportion of 6.8 lbs. per cubic yard (4 kg. per cbm.). The nuisance of flies is done away with in this way, but, at the same time, the fertilizing quality of the sludge is reduced. In Frankfort-on-the-Main, however, the addition of quick lime and chloride of lime has not had the desired result.

Peat is found particularly desirable as a covering, and also to prevent odors, besides aiding the process of drying by absorption of the water. It is used in many places, especially where it is cheap. In order to prevent putrefaction it should be intimately

mixed with the sludge in large quantities. This is not practicable, however, for economic and hygienic reasons.

The use of manufactured deodorants, of which there are several, is more desirable.

Among these "facilol," made by the tar product factory "Biebrich" at Biebrich has been found effective. It is a thin, brownish, light oil with a specific gravity of 0.79. It forms a coherent film of oil when placed upon water, which closes immediately if broken by gas bubbles or sudden currents, preventing the escape of odors. About 28 per cent. of facilol is composed of soluble substances of the phenol group, the effect of which is to prevent putrefaction in sludge and sludge liquor. The eggs and larvæ of insects are also killed by it, while, at the same time, the covering prevents the insects themselves from obtaining their food.

The facilol is sprayed upon the surface of the sludge immediately after its entrance into the basins by a spraying device. The film of facilol is maintained intact by subsequent spraying at long intervals. According to information furnished at Frankfort 0.11 to 0.18 gallons of facilol per square yard (0.5 to 0.8 l per sq. m.) of surface will suffice. The price is about $2.15 per 100 lbs. (20 m. per 100 kg.). This mode of deodorizing, therefore, though efficient, is rather expensive.

As the intensity of the odors increases with the area exposed it might be well to put the sludge to be dried in as deep pits as possible whose bottoms have been drained, and this has, in fact, been tried. The crust of dried sludge which forms at the top prevents the evaporation which assists to a considerable extent in the reduction of water. Openings in the crust permit the air to enter but a short distance. In consequence, the process of drying and also the nuisance of foul odors, which cannot be prevented by subsequent treatment with lime or peat, last for years.

Only when natural pits exist, as at Leipzig, in the shape of an old river bed, and then at some remote point, can this method of drying be used. Moreover, the difficulty of conveying the dewatered sludge partly offsets any saving consequent to dispensing with an artificial drying place.

Odors and the nuisance of flies may be considerably diminished by the means above mentioned so that the conditions are more tolerable for the employees at the plant.

In general, however, it is preferable to remove the drying place from the plant when the neighboring land is occupied, unless a method to be described later be adopted, and to so locate it that it will not be a nuisance to the neighborhood. Land of little value can be used for this purpose and may be correspondingly extensive. Sludge conduits 3000 ft. (1 km.) or more in length have been used for this purpose in Germany. Closed pipes should be used preferably. In selecting a place the prevailing wind should be considered—that it does not blow from the drying beds toward built-up areas.

Drying beds for septic tanks do not require the same restrictions, as there are no odors where the sludge is properly digested.

The time required for drying, and consequently, to a certain extent, the size of the sludge beds, depends:

1. On the composition of the sludge.
2. On the character of the soil or the construction of the bottom of the basin.
3. On the atmospheric conditions.
4. On the method of operation of the sludge basin.

The composition of the sludge, and in particular the amount of moisture contained, determine to a great degree the length of time necessary for drying. For example, 1.3 cu. yds. (1 cbm.) of sludge containing 95 per cent. moisture must have 198 gallons (750 l.) of the water removed before obtaining sludge with 80 per cent. moisture, as is found with septic tanks. A fine, greasy sludge gives up its moisture less readily, and under some circumstances is very difficult to dry; while a thinner and less compact sludge has the opposite characteristic and gives up its moisture easily. The granular, fluid septic tank sludge, as well as that from lignite treatment, has this favorable quality. The deposited sludge from the Kremer apparatus is easily de-watered as it contains so little grease.

A basin with a porous base may be of less size than if compact. If the bottom does not promise free percolation it should be arranged as an artificial filter. Care should then be taken to clean or renew the covering layer frequently.

As evaporation has a marked effect on the drying, this takes place more rapidly in summer. A sunny or windy location is also favorable to drying.

To secure the best results drying should take place quickly on an ample area. The sludge should therefore be distributed in

thin layers—about 6 to 10 in. (15 to 25 cm.). A rapid loss of water through the subsoil occurs, and the cracks caused by drying, plainly seen in Fig. 21, permit the air to pass to the underlying strata. Sludge shrinks in drying to from 2 to 3 to 1 to 2 its original volume. A fresh layer can then be admitted on the dried layer.

Sometimes the sludge is dried directly in the settling tanks. These must then be thrown out of service for some time, as by this method evaporation does most of the work. The time used for drying lignite sludge in this way at Cöpenick is from 3 to 4 weeks. There is a project for the adoption of a similar method at Neustrelitz ("Mitteilung d. Kgl. Prüf. Anstalt," Vol. VI). The size of the necessary basins prevents its use where these are fixed or where there is insufficient land. Special beds for this purpose are always desirable on account of the greater rapidity of drying.

Different intervals are required for drying, depending upon the different conditions mentioned above. As already stated, the septic tank combines the most favorable of these conditions. The length of time required for drying by the Emscher Association, *e.g.*, averages 5 days—with favorable weather only one or two days. Sludge taken from the septic tanks at Halberstadt at intervals of about 8 weeks requires 14 days for drying in good weather. In both cases it is received in thin layers. In contrast to these are those plants where sludge is delivered to the sludge basin to a depth of 2.3 to 3.3 ft. (0.7 to 1.0 m.). The process of drying here usually takes from 6 to 9 months.

In general, normal settled sludge with about 90 per cent. water, requires some 6 or 8 weeks in summer and 6 months in cold weather.

The size of sludge basins can be estimated from the amount accumulated daily and its average time for drying, allowing a certain time for the removal of the dried material. Both factors are subject to great variation with different processes and plants for reasons already given, so that an estimate based upon these figures would have no practical value. As a guide for the area required for drying, the following table, showing the size at different plants, is given; for a great nuisance may result, as has been shown by examples, where these are made too small, while too large an allowance results in too great a cost, especially in the neighborhood of high-priced city property.

SIZE OF SLUDGE-DRYING BEDS

Place	English measures			Metric measures			Method of treatment
	Total	Square yards		Total	Square meters		
	Area Acres	per cu. yd. sludge per day	per capita	Area Hecters	per cbm. sludge per day	per capita	
Brieg................	.74	275	0.14	0.3	300	0.12	Sedimentation wells.
Langensalza..........	2.47	458	1.00	1.0	500	0.83	Sedimentation wells.
Stargard i. P.........	6.17	1905	1.11	2.5	2080	0.93	Sedimentation wells. Much land in reserve.
Ohrdruf..............	0.16	....	1.2	0.066	....	1.0	Sedimentation wells.
Elberfeld.............	6.00	....	0.10	2.43	....	0.08	Sedimentation tanks.
Frankfort............	12.35	183	0.17	5.0	200	0.143	Sedimentation tanks.
Cassel...............	2.47	137	0.08	1.0	149	0.07	Sedimentation tanks.
Munich-Gladbach.....	6.79	420	1.10	2.75	458	0.92	Sedimentation tanks.
Halberstadt..........	1.40	136	0.17	0.57	148	0.143	Septic tanks.
Mülheim a. R.........	0.49	131	0.06	0.2	143	0.05	Septic tanks.
Unna................	0.12	229	0.06	0.05	250	0.05	Septic tanks.
Emscherbrunnen......	....	46–55	0.02	....	50–60	0.02	Septic tanks
Rochdale............	0.22	....	0.18	0.09	....	0.15	Sedimentation and septic tanks.
Leeds-Knostrop.......	22.23	275	0.25	9.0	300	0.21	Precipitation with lime.
Accrington...........	2.22	916	0.22	0.9	1000	0.18	Septic tanks.

The size of drying beds is governed by the amount of sludge which accumulates during the time required for drying, the reasons for this time being given.

There is a great difference, therefore, between the size required for plain sedimentation and that required for septic treatment. Imhoff gives in Vol. VII of "Mitteilung der Kgl. Versuchsanstalt" the following rules for size, based upon his observations:

For septic tank sludge 275 sq. yds. per cubic yard (300 qm. per cbm.) daily of sludge received, and therefore for an amount of .0004 cu. yds. (0.3 l.) per capita daily, 0.12 sq. yds. $\left(\frac{0.3 \times 300}{1000} =\right.$ about 0.1 qm.) per capita.

For sludge from plain sedimentation 458 sq. yds. per cubic yard (500 qm. per cbm.) daily of sludge received, and therefore with .0016 cu. yd. (1.2l.) of sludge per capita daily, 0.72 sq. yds. $\left(\frac{1.2 \times 500}{1000} = 0.6\right.$ qm.).

The latter values agree with the table, while the former appear too high, so that with septic sludge about 183 sq. yds. of drying surface will be necessary for 1 cu. yd. of sludge per day (200 qm. per cbm.) and 0.072 sq. yds. $\left(\frac{0.3 \times 200}{1000} = 0.06\right.$ qm.) per capita. This shows clearly the advantage of septic tanks as compared with plain sedimentation, both on account of the smaller amount of water contained and the smaller amount to be evaporated.

The values in the table naturally indicate marked differences in different cities. This is due in part to the different methods of treatment and handling and partly to the fact that the operation of drying beds where space is limited must be much more intensive than where the opposite conditions obtain, in which case the sludge remains longer than necessary, until it is convenient for the farmers to remove it.

An estimate of the size of sludge lagoons based upon the daily flow of sewage would result in yet greater differences and is therefore not given.

b. Drying by Filter Presses

De-watering sludge by filter presses was first tried in England about 30 years ago, and was soon in general use there. The large volumes of sludge which resulted from chemical precipita-

tion, then in general use, and the odors from these plants which were especially unpleasant in thickly populated districts, led to a rapid spread of this method of drying. In default of other methods its disadvantages were willingly overlooked.

In Germany, also, sludge presses are found almost exclusively in plants where chemical precipitation is or has been employed, except in the lignite process, which should be included here.

Filter presses consist of a large number of thin cells, usually about 2.3 to 3.3 ft. (0.7 to 1 m.) square and 2 in. (0.05 m.) thick. According to the design of the separate parts which compose these cells they are called cell presses or frame presses. In the former the partition plate between two cells is provided on each side with rims projecting about 2 in. (5 cm.) (Fig. 23) so that the

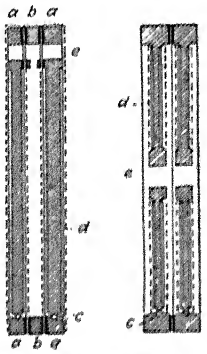


FIG. 22. Frame press. FIG. 23. Cell press.

edge of adjacent plates by coming in contact form a hollow space between. In the frame presses these plates are of uniform thickness (a) and to form the cells a frame is inserted between two plates (b). This forms, at the same time, the narrow walls of the cell (Fig. 22). These plates or partitions in the cell press are provided with numerous grooves opening below into a horizontal hole (c) which serves as a channel for the liquor pressed out. Over these plates are placed sieves, and over these filter cloths are stretched, or possibly the latter only (d) are provided, so that in filling the cells with sludge the surplus water will pass through the cloth and run down the partition plates in the grooves. It then leaves the press through the ducts (e). The separate plates are supported by lateral projections on horizontal bars and are pushed together by hand. The water-

tight contact is then accomplished by means of a screw or by the plunger of a hydraulic press. The influent channel (e) lies either in the upper edge or the middle of the plate. In the former case, the sludge can be introduced at several points by flexible pipes, while in the latter it must be done at the middle of the front plate.

In frame presses the filter cloths are simply hung over the entire frame so that they cover both sides and are clamped at the edge by the adjacent frame. In cell presses, on the contrary, the edges of the cloths laid in the recess between the plates must be made water-tight in a special way. The filter cloths are rapidly destroyed by rotting, which is most active at the top of the solid plates, as the damp cloths are here always in contact with the air. Saturation with tar at this place prolongs their life, which is generally about 4 weeks.

The frames may be made of iron or wood. The latter is preferable for sludge presses, as iron rusts easily from acids that may occur in the sludge. The number of plates varies, but 50, each, of plates and frames would be the maximum.

The delivery of the sludge and the necessary pressure of 3 to 8 atmospheres for pressing can be provided by a sludge pump or compressed air. The sludge pump can work directly on the press, as *e.g.*, at Halle. A relief valve must then be inserted in the sludge press pipe which permits the surplus sludge to pass off from a fairly full press, where, therefore, only a small amount of sludge, as compared with the volume of the liquor drained out, can be received. This surplus sludge, as well as that remaining in the pipe after filling, then flows into a special sludge well and is the first to be pumped out before refilling. During the emptying of the press, which lasts from 10 to 30 minutes, the delivery of sludge from the well must cease.

Otherwise we may provide a sludge receiver (Spandau), which is filled by the sludge pump while discharge takes place by air pressure. The sludge receiver can be filled by suction and the contents then forced out into the press by air pressure. This method permits uninterrupted operation by installing two receivers, side by side, as already described for propelling sludge. The presses can be operated to greater advantage by the use of sludge receivers. Therefore this method is always to be preferred for large volumes of sludge to the slower method of filling the presses with a pump. The employment of a stirring device,

particularly with long, extended receivers, is not desirable or necessary; as it is impossible to support the shaft properly by means of intermediate bearings.

To empty the presses [which yield an average of about 2.6 cu. yds. (2 cbm.) of sludge cake for each filling] the frames are pushed apart. The sludge then drops into a tip-car placed below, or into a channel. The contained moisture is reduced to about 50 or 60 per cent. Further drying in the air should be given the sludge in covered chambers, as otherwise it decomposes, especially in wet weather. If allowed to lie for any length of time in the open it is well to cover it with a layer of earth or sod to prevent objectionable odors.

Emptying presses is a dirty operation, and in summer, especially, it produces very foul odors which can only be prevented by thorough ventilation of the press chambers. Water under pressure is absolutely necessary for rinsing purposes. Sometimes the filled presses are allowed to stand several hours after filling, even 12 hours in Oberschoenenweide, to give more consistency to the sludge.

As settled sludge is never very firm, the advantage in chamber presses that the contents fall out when they are opened, while frame presses require subsequent cleansing by hand, is offset by the difficulty in fastening the filter cloths. Frame presses are therefore to be preferred for pressing sludge.

The liquor drained from the press is very putrescible, and to be clarified should be brought to the influent conduit again or should be used in irrigation.

Sludge from domestic sources that has been obtained by mechanical processes cannot be pressed. A large part of the finest particles of this very watery sludge passes through the filter cloths, robbing the sludge cakes which remain behind of their binding medium, so that when the press is opened, the sludge is found in an incoherent mass. Greasy or slimy sludge may also prevent pressing by clogging the cloths. Sludge from septic tanks, on the contrary, can often be pressed without any further treatment, if it has not lain too long in the tank. The same is true of sludge from the lignite process, which is almost always successfully de-watered by the filter press. Chemical precipitation, however, is the principal treatment for which sludge pressing is used, as the precipitants employed render the sludge cakes cohesive.

A dose of lime is necessary to make an unfavorable sludge capable of being pressed. 8.4 lbs. per cubic yard (5 kg. per cbm.) is sufficient, or 5 per cent. of the dried material in the sludge. This addition is also sometimes necessary after chemical precipitation. Of the English cities, Chorley adds 8.4 lbs., Blackburn 8.4 to 13.5 lbs., Bury 10.1 lbs. per cubic yard (5 kg., 5 to 8 kg. and 6 kg., respectively, per cbm.) to the sludge obtained by alumino ferric as precipitant. With greasy deposits these amounts must often be increased. At Willesden it is 37 lbs., at Colchester 47 and at Ealing even 84 lbs. per cubic yard (22 kg., 28 kg. and 50 kg. per cbm., respectively), in order to secure hard cakes, which can then be incinerated.

The necessity of adding some substance to obtain a sludge that can be pressed has helped to retain the use of chemical precipitation in England, for it is more reasonable to use lime in the clarification process than to add it merely for pressing. The addition of lime reduces the cost of pressing, but increases the total cost of clarification. Dunbar gives an excellent example of this (*Leitfaden für die Abwassereinigungsfrage*). In Wimbledon, by using lime and iron precipitants, 8.5 tons of sludge cake per million gallons of sewage cost 53.4 cts. per ton (2 long tons per 1000 cbm. cost 2.51 M. per long ton) for pressing, or about $4.50 per million gallons (5 M. per 1000 cbm.) of sewage. By adding lime this was reduced to 36 cts. per ton (1.68 M. per long ton). But 12.7 tons per million gallons of sewage (3 long tons per 1000 cbm.) of pressed cakes were obtained, so that the cost of pressing per million gallons of sewage was as high as before. The cost of the additional precipitant was included, in addition to which 1 1/2 times the volume of sludge was obtained. The questions of cost and increase of sludge are to be considered in increasing the precipitant, for it is not reasonable to add precipitants merely to secure sludge which can be pressed without increasing the clarification.

Sometimes very greasy sludge refuses to take up the lime, and de-watering must be accomplished in some other way. This has been the case in several English cities.

In Frankfort-on-the-Main, too, the filter presses have been abandoned, for it was found on opening the presses that, even with great pressure, only the layer next the cloths had been de-watered and caked, while the middle of the chamber was full of liquid sludge. A satisfactory result was only obtained after

adding 9.5 lbs. (4.3 kg.) of sulphate of alumina while, at the same time, heating the press. This increased the cost to $1.00 per cubic yard (5.50 M. per 1 cbm.) of sludge, rendering any practical use of the method prohibitory.

The cost of pressing 1 ton of cakes obtained from 5.8 cu. yds. of watery sludge in English plants, including interest and sinking fund charges, is, according to Schiele, $0.42 1/2 to $1.28 or an average of about 85 cts. (1 long ton from 5 cbm. sludge, 2.00 to 6.00 M. or an average of about 4 M.). Reichle and Thiesing give for the same amount about $0.49 (2.30 M. for 1 long ton) as the cost of pressing under German conditions, assuming the cost of the press at $1785 (7500 M.) and amortization at 5 per cent. But an extra dose of lime is not included. This last estimate assumes the most favorable operation of the presses, so that the price per ton of pressed cake in Germany may be taken at about 63 1/2 cts. to 85 cts. (3 to 4 M. per long ton).

For the addition of lime, usually in the form of milk of lime, in England, a tank is inserted between the sludge pit and the sludge holder by the presses, in which the sludge remains quiescent for a short time, sometimes for several days, after the dose of lime has been added.

With modern plants it is seldom necessary to resort to presses for de-watering. The advantages of the short time and the limited space required for drying as compared with drying in the air, are offset by the greater cost. The nuisance due to foul odors is reduced, but not entirely eliminated, and the workmen have to come into contact with the sludge to a considerable extent.

The lignite process is accompanied by a minimum of offensive odors and as it is more favorable for pressing on account of the addition of chemicals, this method has been retained here. These plants are particularly adapted for use in thickly populated districts on account of their arrangements, such as the complete enclosure of the sewage during clarification in towers, etc. The greatest importance naturally is attached to a quick removal of the water, the occupation of but little room, and a prompt disposition of the sludge, which is in this case effected by incineration.

c. De-watering Sludge by Centrifugal Machines

The disadvantages of filter presses led to experiments with other mechanical appliances for de-watering sludge. Drying by

centrifugal machines, such as are used in laundries and bleacheries, seemed to promise the best results.

The water that is drawn off by centrifugal force from the material to be dried passes out through the sieve-like sides of the rotating drum.

This process did not, however, give the hoped-for results. In the first place the finer particles of sludge were thrown out through the perforated or cloth-covered sides. In the second place the heavier portions were thrown against the sides of the drum by the centrifugal force so compactly that after a while no more water could penetrate it.

Sludge is so disintegrated by the centrifugal action that the heavier portions—the mineral ingredients—go to the outside. The organic materials come next in concentric layers, while the liquid portion remains in the middle with the grease on its surface.

This behavior of the sludge led to the construction of a centrifugal machine similar to those used in milk separators, with a solid shell, the water being led off as by a siphon. This method required a long time, as was demonstrated by experiments at different places (Spandau, Frankfort-on-the-Main, Mannheim. In Spandau with sludge from the lignite process, 30 to 45 minutes). Besides the solid ring of sludge collected at the shell had to be cleaned out by hand with a spoon-shaped instrument at the end of each period of operation.

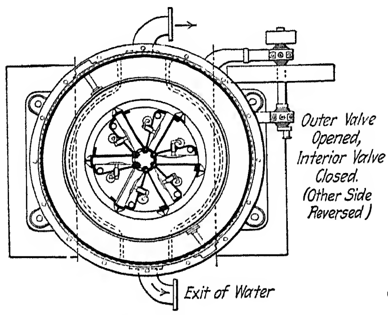
In experiments made with such a machine at Chemnitz, furnished by the Haubold machine works of that city, 3 cu. yds. (2.5 cbm.) of sludge was de-watered in about 10 minutes from 90 per cent. to 45 per cent. or 60 per cent. reduction of moisture as described in Schmeitzner's "Clarification of Sewage." It required 6 h. p.

An attempt was made to circumvent the dirty, slow and unhealthy work of cleaning, which prevented its adoption in large plants and, in addition, lessened the efficiency of the machine, by introducing a bottom which could be lowered and the automatic ejection of the sludge. The cost remained high, however, on account of the length of time required, although as to the quality of the product, the results secured were satisfactory. The addition of 1 per cent. of lime to bind the grease, thus improving the material to be ejected as well as the liquid effluent, was found useful.

The entire process can only be of practical use if the wet sludge

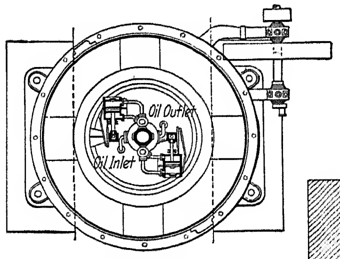
can be brought in and the dried sludge removed automatically without stopping the machine, while reducing the time required for the work.

These conditions have been fulfilled by the Hanover Machine Co., formerly G. Egestorff, at Hanover-Linden, in a centrifugal machine placed on the market as the Schaefer-ter Meer System (German Patent) which was constructed after many experiments by Director ter Meer in conjunction with City Engineer Schaefer, Frankfort-on-the-Main.



Section A–B.

Fig. 25.



Section C–D.

Fig. 24.

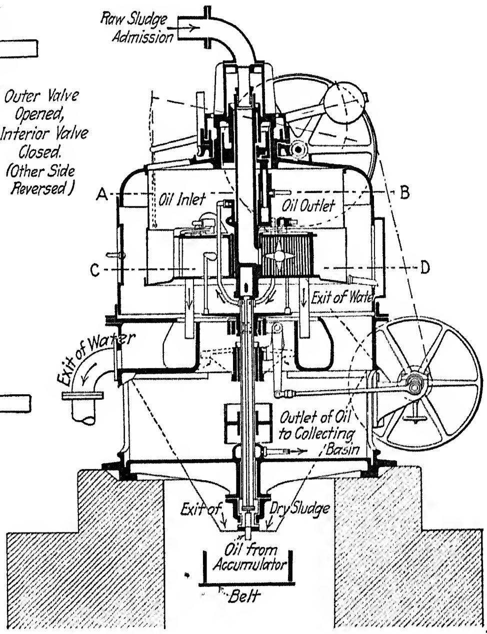


Fig. 26

Figs. 24, 25 and 26.—Centrifugal machine.

Two of these machines have been in use in Harburg, four in Hanover and six in Frankfort.

As this system has been found of practical value for some time, we will consider its operation in more detail.

The part of the apparatus which collects the sludge while throwing off the remainder, consists of six radial chambers, having a rectangular cross-section (Figs. 24 and 25), one radial side of which is formed by a sieve-like plate. This has slits 0.4 in.

(10 mm.) long and .016 to .024 in. (0.4 to 0.6 mm.) wide. The chambers are closed on the inside and outside by slide valves and have a capacity of about 1 to 10 cu. ft. (3 l.) each.

The process of ejection is as follows: the wet sludge flows from a receiver placed at a higher elevation through the central inlet pipe into the chambers while these are in rotary motion. The inner valves are thereby opened and the outer valves closed. The heavier particles of sludge are now thrown against the outer part of the chamber, by which action the water is forced inward, partly by the compression of the mass and partly because of its lighter weight, and flows out through the sieves to the surrounding water chamber. From this it passes through short pipes into a circular gutter and thence to the outlet (Fig. 24).

Sludge takes the place of the water thrown off until the chamber is quite filled with the de-watered material. The inner ring valve is then closed preventing the admission of any more sludge, and the entire mass is then whirled around for a period depending upon the composition of the sludge. The outer valves then open and the dried sludge is thrown out by the centrifugal force. It flies against the wall of the shell, being loosened up and disintegrated, and then falls down and out of the apparatus onto a belt conveyor.

Between the outer valves and the wall of the shell is a circular movable impact wall. This serves to intercept any water that might escape during the process of ejection through the outer valves, which may not be tight, keeping it away from the dried sludge and the conveyor. It is raised a short time before the valve is opened, to leave the way clear for the sludge to be thrown out.

After the chambers have been emptied, the outer valves close again, and as the inner ones open, the chamber is again filled with wet sludge and the operation is repeated.

The separate movements are quite automatic and even the operation of the valves is governed through two cylinders by means of press oil (Fig. 26) which is stored in an accumulator by means of a special pump. This also serves as a bearing to support the pressure of the centrifugal drum shaft. The admission of the press oil into the moving cylinder is regulated by a regulating valve.

The sieve surfaces are cleaned partly by the passing through of the dried material when being ejected, partly by special

scrapers which are operated mechanically by the regulating apparatus.

The ejecting drum makes 750 r. p. m., corresponding to a circumferential velocity of 105 ft. (32 m.) per second.

The length of a working period in the experiments made by Reichle and Dr. Thiesing at the Harburg plant ("Mitteilung der Kgl. Prüfungs-Anstalt," Vol. X) averaged 2.5 minutes, or 3.5 minutes at the most. In the plant at Hanover the standard time is 1.5 minutes, though this may be increased to 5 minutes when the sludge is very slimy.

In order to dry successfully by centrifugal force, the contents of the sludge should be somewhat heavier than water, as the entire action depends upon the stronger repulsion due to the greater specific gravity of the material. The fine particles of sludge separate themselves out from the sewage and adhere to this heavier material on account of their sticky nature. Fresh sludge is therefore easier to work over than that which has decomposed, as the proportion of fine particles has increased in the latter by disintegration.

The efficiency of a centrifugal machine varies according to the composition of the raw sludge. 2.6 to 5.2 cu. yds. (2 to 4 cbm.) of raw sludge can be de-watered in an hour when 20 to 33 gallons (75 to 125 l.) of wet sludge is admitted to the chamber at each filling.

In the experiments at Harburg 1 cu. yd. of raw sludge with about 92 per cent. of moisture yielded an average of 294 lbs. of ejected sludge (175 kg. per cbm.) or 634 lbs. (287.5 kg.) per machine per hour. This contained 69.7 to 74.2 per cent. of moisture and the dried material contained a somewhat larger proportion of mineral matter than the raw sludge, but much less grease (8.5 per cent. instead of 14.2 per cent.).

The efficiency of the centrifugal action, *i.e.*, the ratio of the actual volume of ejected sludge to the dried material in the raw sludge, computed on the basis of the water contained in the ejected sludge, ranged, in the Harburg experiment, 46.3 to 69.8 per cent., averaging 60 per cent. According to experiments at Frankfort and the above observations at Harburg, this figure should be somewhat greater. It should preferably be taken somewhat greater because the amount of dissolved material, which will inevitably reach the outlet, must be deducted from the dried material in the raw sludge.

Fully 60 per cent. of the dried material contained in sludge is, therefore, removed by the centrifugal action, while about 40 per cent. is returned to the clarification plant by the effluent and must be treated again. The volume of accumulated sludge is thus increased as well as the concentration of the drainage water, diminishing somewhat the efficiency of the clarification plant.

The ejected sludge contains about 2 to 3 of the mineral matter and 1 to 3 of the organic matter of the raw sludge as the following table, compiled from observations at Harburg, indicates:

TABLE SHOWING RESULT OF CENTRIFUGAL ACTION ON:

a. One Cubic Yard of Raw Sludge

	Total weight lbs.	Water lbs.	Total dried material lbs.	Ash lbs.	Organic matter lbs.	Grease lbs.
Raw sludge......	1720	1584	134	29.4	104.8	19.1
Ejected sludge....	295	214	81	20.1	61.0	6.9
Effluent..........	1423	1370	53	4.7	48.1	

b. One Cubic Meter of Raw Sludge

	Total weight kg.	Water kg.	Total dried material kg.	Ash kg.	Organic matter kg	Grease kg.
Raw sludge......	1019	939.6	79.4	17.4	62.0	11.3
Ejected sludge....	175	126.6	48.1	11.9	36.2	4.1
Effluent..........	844	812.7	31.3	2.8	28.5	

The effluent contained on an average 3.7 per cent. of dried material, composed of 9 to 10 organic and 1 to 10 mineral matter.

The large amount of organic matter renders it very putrescible, producing foul odors even during its separation. At Harburg it is returned to the main sewer and mixed with the sewage. At Hanover, on the contrary, it is conveyed to two tanks which have been emptied. These are first filled with the liquid which has been thrown off, which is then carried beyond in the usual manner.

If the sewage receives further treatment on irrigation fields or in contact beds the centrifuge effluent can be treated with it. In large plants there may be some question of treating it in septic tanks; but where there is abundant water for dilution it may be discharged into it directly.

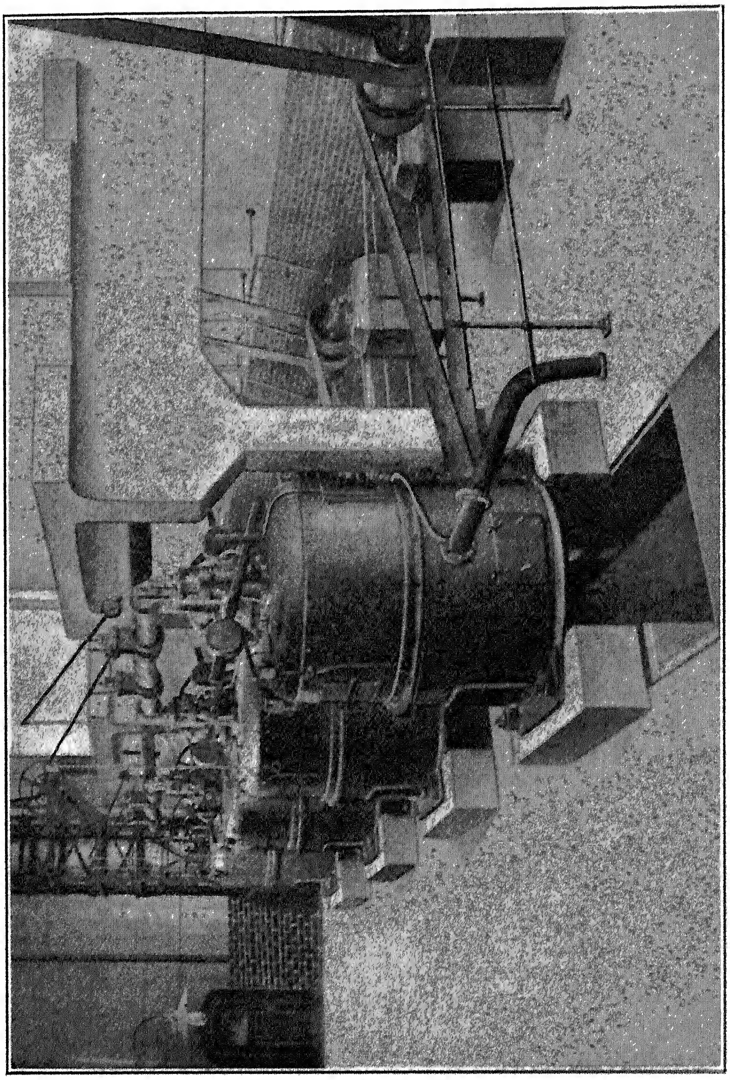


FIG. 27.—Sludge drying machine at Hanover.

A sludge holder constructed of plate iron or reinforced concrete (Fig. 27, upper right hand) and provided with a stirring device should be placed above every two centrifugal machines, so that the material received may be as uniform as possible. The holders should be large enough to contain all the sludge accumulated in a day, so that the tanks can be emptied of sludge independently of the centrifugal machine and can be ready for use again in the shortest possible time.

A screen of about .4 in. (10 mm.) mesh should be placed before the sludge holder in case none has been provided before the tank or at the pump well, to intercept any coarse material which might interfere with the operation.

The dried sludge falls on to a belt which passes below the centrifugal machine, and at Hanover, for example, is brought to an elevator (Fig. 27 in the background) which carries the sludge to a reservoir similar to a silo. It has been observed, however, that the sludge forms a compact mass in spite of the very steep slope of the bottom, and can only be discharged into the car below by manual assistance. When the plant was visited the sludge was allowed to fall through a gate in the bottom directly into an enclosed car for its conveyance, holding about 2 cu. yds. (1.5 cbm.) It is advisable, however, to omit the elevator, which requires considerable power, and to raise the sludge the short distance to the top of the car by the required inclination of the belt conveyor. The introduction of a small hopper which can be closed is of advantage in order to hold the sludge while the cars are being changed. In certain cases the car can be placed directly under the centrifugal machine.

The whole plant will require about 12 h. p. per machine.

The centrifuge alone will require about 7.2 h. p.

If a suction producer gas plant is employed for power, costing about 1.2 cts. (5 pfg.) per h. p. hour, the cost of operating a centrifugal machine would be 8.6 cts. (36 pfg.) per hour; or, with electricity at 1.2 cts. (5 pfg.) per kw. hour, only 7.6 cts. (32 pfg.). This would correspond to a cost for current of 5.13 cts. per cubic yard (0.28 M. per 1 cbm.) of raw sludge or 35.2 cts. per ton (1.63 M. per 1000 kg.) of the product.

The ejected sludge is of a loose, crumbly consistency and consequently dries readily. Its weight is 1520 lbs. per cubic yard (900 kg. per cbm.). The tendency to putrefy is comparatively slight if it is sheltered from rain and sunshine, but it is, naturally,

not entirely done away with as there still remains much organic matter that is not fully digested. When collected in large heaps its temperature rises and it becomes more compact.

The centrifugal process reduces the volume of the sludge to about 1/6 of the original amount, when the product contains about 55 to 70 per cent. of moisture.

The apparatus requires but little attention as the filling and emptying are automatic, so that one attendant suffices for two machines. He does not come into direct contact with the sludge, as the machine is entirely enclosed.

In this way all foul odors are avoided, especially as the process requires the sludge to be as fresh as possible.

Drying is rapid and the sludge is soon in favorable condition for further manipulation.

The only drawback is the high cost of the plant and its operation. The cost of the centrifugal apparatus with the stirring devices and the oil pressure pump is about $5230 (22,000 M.) with an additional $240 (1000 M.) for the motor. Estimating 5 per cent. for amortization and the price for electric current already given, and we have as the expense, including wages, polishing material and reserve sieves, with a maximum use of the apparatus, 62 cts. per ton (2.87 M. per 1000 kg.) of the product for drying, or fully 10 cts. per ton (50 pfg. per 1000 kg.) more than with filter presses under similar conditions. (See page 69.)

The cost of de-watering is naturally least with drying in the air, especially as the cost of the plant can be greatly reduced by a simple construction of the drying beds. And although, as estimated by Reichle and Thiesing, drying with filter presses may be cheaper under similar conditions, this is offset by the necessity of adding chemicals to the sewage, which is, as a rule, not necessary in order to obtain a sufficiently clear effluent.

The centrifuging of sludge is particularly advantageous in the case of simple sedimentation, where it is desirable to secure a rapid reduction of moisture or where the establishment of drying beds is not feasible, for lack of room or other reasons.

d. Other Methods of Reducing the Water in Sludge

Some methods will be alluded to here which are employed for merely a slight reduction of the moisture preparatory to further drying, or which have not yet passed beyond the experimental stage.

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d. Other Methods of Reducing the Water in Sludge

Some methods will be alluded to here which are employed for merely a slight reduction of the moisture preparatory to further drying, or which have not yet passed beyond the experimental stage.

A part of the water may be drained off by letting the sludge settle again and drawing off the roily water which has separated out above the sludge. This can be accomplished in sludge wells or in special sludge holders, such as are inserted before filter presses for mixing the lime, for example. The reduction of water is naturally slight, and is only worth considering with a very watery sludge, such as is obtained by movable contrivances for drawing it off under water. On the other hand, it is unreasonable to construct special plants for this purpose, especially as the very dirty turbid liquid, on account of the necessity of subjecting it to further treatment, is detrimental to the operation of the plant. Moreover, the settled sludge should not be stored without some special reason, as the freshest possible sludge is the best for subsequent drying by mechanical means.

It may be considered, however, where, as in Allenstein, a vacuum receiver can take in the whole of the day's supply at one filling. This, coming from wells, remains in the receiver one day. The turbid water which separates out is then drawn off through faucets at different heights in the receiver, before the sludge is propelled further. This results in a desirable reduction of volume, especially when it is conveyed to the fields in a wet condition.

As has been several times mentioned, sludge loses a part of its water during septicization, and acquires a more favorable character for further drying in the air. The aim should therefore be to convey the sludge from the sedimentation tanks to special digestion chambers, in some cases with admixture of a portion of the unclarified sewage (Skegness, Eng.). This is done, *e.g.*, at Columbus with the sludge from grit chambers and sedimentation tanks. It is only advantageous where contact beds or artificial or natural sand filters which are already installed for the rest of the plant, can be used to purify the effluent. Should these devices be installed and operated merely for the digestion of the sludge, the cost would be out of proportion to the comparatively slight improvement due to the digestion.

By leaving it to digest the sludge may be stored up for such times as it is required for fertilizing the land.

A certain amount of digestion also takes place by drying in the air, as indicated by the generation of gas.

This favorable alteration in sludge is readily brought about in the Emscher tank, already mentioned, by combining the

settling tank with the digestion chamber, and without obtaining a putrescent effluent or being annoyed by disagreeable smells. The gases of decomposition contain only traces of sulphuretted hydrogen, being chiefly composed of methane and carbonic acid, and are therefore almost odorless.

The decomposition here differs favorably from that in septic tanks without a current, as is usually the case with those for the digestion of sludge, by its greater intensity. The reason, according to Spillner (Ges. Ing., 1909) is probably that fresh sludge is constantly admitted and so there is no lack of bacteria and their nourishment. At the same time, with the frequent removal of the sludge, and in exchange for the fresh sludge, the disintegrated product, which is harmful to bacteria, is removed. The septic chamber is, moreover, always in operation, and the disadvantage of receiving undigested sludge when sludge is drawn off is obviated. This occurs if the septic tank is not allowed to rest for several weeks after shutting off the inflowing sewage.

A very different process from any mentioned is the patent electro-osmose method of Count von Schwerin, with which exhaustive experiments have been made in the drying and utilization of sludge at Frankfort-on-the-Main.

In this process the liquid molecules, by osmosis, pass to the cathode, while the solid particles collect at the anode, when an electric current is passed through a mass of sludge. The separated water at the cathode is then drawn off. The colloids, which form a large part of the sludge and which render drying by mechanical means difficult on account of their slimy consistency, are shriveled up by the electric current, facilitating their separation.

The apparatus consists of frames, one side of which is enclosed by a brass sieve which forms the cathode, and the other by a metal plate, usually of lead, which forms the anode. The inside chamber is filled with sludge and the anode plate is brought near the cathode. The anode plate approaches the cathode as the volume is lessened by the drawing off of the water at the cathode.

Electrolytic disintegration is brought about simultaneously by the electrolite contained in the sludge, so that the cathode water is alkaline, while at the anode the reaction is slightly acid.

The current used in this method, which is not yet past the

experimental stage, is rather high, but not so great, according to Tillmans, as to render it impracticable.

Artificial drying over a fire is entirely out of the question for wet sludge for reasons of economy, on account of the great volume to be converted into steam; but it has been tried with sludge made somewhat firm by air drying or by filter pressing.

The cheapest way of doing this is by making briquettes of the solid sludge in brick presses, which are then dried on shelves under a roof, and in from 2 to 8 weeks, according to the weather, become sufficiently hard to be transported without special precautions. These sludge bricks can then be ground up and used as a fertilizer.

The process of artificial drying consists either in carrying the sludge on a belt conveyor through a heated chamber, or it is brought to a current of hot air, by an enclosed worm conveyor, in a slowly-revolving iron drum. The foul gases which arise are led under the fire to render them inoffensive.

The value of the material as a fertilizer does not compare with the cost, especially of the coal, as will be shown later; so that such a method is quite impracticable, aside from the disagreeable and unhygienic features of the work due to the odors created, and repeated contact with the sludge.

CHAPTER V

Utilization of Sludge

Ever since the impure matter has been separated from sewage in the form of sludge by clarification plants, suggestions and experiments of various kinds have been made toward the most complete and profitable recovery, so far as possible, of its more valuable constituents.

The following conditions should be fulfilled in any process leading to the utilization of sludge:

1. The operation should take as little time as possible, and there should be a complete removal of injurious ingredients.

2. No physical harm or inconvenience should be permitted to come to the workmen or to the neighborhood of the works.

3. The more valuable materials in the sludge should be extracted or recovered to the fullest extent.

4. The process should be economical—*i.e.*, the cost of operation should not be greater than is justified by the anticipated benefits.

1. Hygiene demands that, on account of the nature of sludge, the filth obtained from sewage should not be stored up or subjected to long drawn out manipulation, especially when the previous treatment is unobjectionable. The objectionable substances should be removed or altered by the operation, so that the final product is inoffensive.

2. The immediate contact of the workmen with the sludge should be avoided here, as in its removal from the tanks and its drying, for fear of infection. The generation of gases and disagreeable smells in the utilization of sludge may result in a nuisance to the neighborhood, as has been mentioned in connection with drying.

3. As the amount of the more valuable materials in sludge is small, so that large quantities, as compared with the amount of the product, must be handled, economy demands the greatest possible recovery without any waste. It is to the general interest that none of the material representing any considerable value in the large volume of sludge collected from many sources should

be lost, especially in view of the successful efforts that have been made in all branches of human endeavor to recover that which was formerly considered worthless.

4. The hope of securing a revenue from sludge utilization equal to the cost of operation, or of making it a profitable undertaking, has long been destroyed, at least with city sewage.

This is easily understood when one considers that in a city of 50,000 inhabitants with an output of 2 million gallons (7500 cbm.) of sewage per day, perhaps 58.5 cu. yds. (45 cbm.) of sludge, 90 per cent. moisture, or 5.9 cu. yds. (4.5 cbm.) of dried material are recovered, of which possibly 2.6 to 3.3 cu. yds. (2 to 2.5 cbm.) are of organic origin—about 0.3 per cent. of the total volume of the sewage. This small proportion represents the really valuable material, which has a possible theoretical value of from $7.14 to $9.52 (30 to 40 M.) and must often be obtained by elaborate treatment. Sometimes the cost of the plant is recovered by the valuable ingredients found in the wastes from certain industries—wool-washing or metal working, for instance—but the plant should then be used only for these valuable wastes. Sometimes the income is even in excess of the expense.

The incalculable benefit derived from a rapid removal, as well as the expense resulting were any other method employed, should be added to the income earned, together with the proceeds from the product obtained. The same thing is true regarding losses which may accrue from depreciation of the neighboring land, or demands for damages. These may amount to large sums, according to the location of the plant, and possibly result in an entire change in the method of treatment.

In calculating on a possible revenue from any method, care should be taken to estimate the probable selling price of the product, or the value of the ingredients of the sludge which are to be utilized. Above all, one should note the difference between the theoretical value as worked out on paper and the actual value, neglect of which has often necessitated the abandonment of a process which, on paper, gave promise of a large revenue. The existence of an ample demand for the product should also be considered.

On account of the advantages mentioned, which it is often impossible to express directly in dollars and cents, but which nevertheless accrue to a city in the form of improved hygienic

conditions, or by reducing the operating charges, private enterprises must always be at a disadvantage, even when, as is frequently the case, the sludge is delivered to them just as it is obtained, without cost.

The utilization of sludge may be accomplished in the following ways:

a. By availing of its fertilizing value.
b. By availing of its calorific value through incineration.
c. By the gas produced.
d. By the grease obtained.
e. By various other methods of disposal.

Those methods are comprised under e which are of minor importance, or which seek merely to render sludge inoffensive without reference to its commercial value.

It must be emphasized that none of the methods as yet employed entirely fulfill the conditions mentioned at the beginning of this section.

a. Utilization of the Fertilizing Properties of Sludge

The principal field for the use of settled sludge is as a fertilizer in farming operations. This is the most ancient and was, formerly, the only use.

In the future the greater part will also be utilized in this way, especially in small places where the cost of plants for further treatment would be too great and where the small amount of sludge produced would not admit of its utilization. Other conditions there, too, are found to be most favorable for this disposition of sludge.

The value of sludge as a fertilizer depends chiefly upon the amount of nitrogen and phosphoric acid contained; also, in less degree, on the amount of potash. The first two each comprise about 1.5 per cent. of the dried material in settled sludge, potash about 0.5 per cent. These figures naturally vary with sludge obtained by different processes. They are, therefore, not to be given equal weight in their consideration for agricultural purposes.

Detritus from grit chambers has little fertilizing value and is used principally for filling in land, also for the top dressing on irrigation fields. It is, however, sometimes mixed with the sediment from tanks to avoid the expense of the separate transporta-

tion of these small quantities. Sludge from chemical precipitation and septic tanks possesses but little fertilizing value. If lime is used in the former it can be employed where the soil is lacking in this ingredient. Sedimentation processes and bar and mesh screens furnish sludge of the highest value, especially the last, as the detritus from these is almost wholly organic, while about one-half the dried material of settled sludge is organic.

The fertilizing property of settled sludge is often unfavorably affected by the grease contained. This prevents disintegration, to a great extent, and injures the soil by the formation of a coating not readily pervious to air or water.

With greasy sewage a separation of the grease, as in the Kremer apparatus, is of great advantage in the sale of sludge for agriculture.

The amount of material valuable for the nourishment of plants, mentioned above, corresponds to a theoretical fertilizing value of 28 cts. per cubic yard (1.50 M. per cbm.) of wet sludge containing 90 per cent. moisture, and $1.10 per cubic yard (6 M. per cbm.) of dried sludge with 60 per cent. of moisture. With an amount of sludge equal to 0.786 cu. yd. of sludge per 1000 persons (0.6 l. per capita) daily, or in round numbers, 290 cu. yds. per 1000 persons (220 l. per capita) per year, the income would be $78.50 per 1000 persons (0.33 M. per capita) annually, which would cover the greater part of the operating expenses—with sedimentation processes, under favorable circumstances, the whole.

But this is not the case. The cost of transportation to the place of utilization should be deducted from this theoretical value. This is not insignificant, as much water must be carried, even when the sludge is quite firm, aside from the sandy portions which are useless for fertilizing.

The fertilizing material in sludge cannot be wholly utilized, as is the case with sewage irrigation; for the proportion available as plant food yields an excess of nitrogen. With grain this results in an abundance of straw, but few shriveled grains. If, then, the nitrogen is to be entirely utilized, either one must not apply too much sludge, unless vegetables only, or leafy plants, are to be raised, or else the lime and potash which are lacking must be brought to the field independently.

For these reasons the actual value is much less than the theoretical. Moreover, artificial fertilizers are now much cheaper than formerly and are preferred, because more easily handled.

The night soil from towns not provided with sewerage by water carriage is superior to sludge for its fertilizing properties. Sludge can only be used for agricultural purposes in the fall and winter up to the time of spring planting, as the nitrogen is deleterious to most plants after May and, moreover, the teams for hauling are otherwise employed. A constant removal is desirable for clarification plants. Only plants with septic treatment are adapted to annual or semi-annual removal.

It is impossible to secure high prices, as farmers are not dependent upon sludge for fertilizing, while the treatment plants demand constant removal and the storage of sludge, except in small quantities, is objectionable.

Sludge is utilized as a fertilizer either wet or in a de-watered condition, or the drying may be carried to such a point that it can be strewn over the ground.

1. The use of Wet Sludge as a Fertilizer

When wet the sludge can either:

1. be taken to the fields in casks or water-tight receptacles, or
2. conveyed thereto in pipes or open channels.

The first method is particularly advisable where, in small plants, the sludge is removed from the settling tanks to a wagon by suction, or by pneumatic apparatus such as is used for emptying cesspools. All bad odors are thus avoided, and also the nuisance of flies. The sludge treatment plants are, too, reduced to a minimum, as no additional apparatus is necessary. A previous drawing off of the turbid liquid in the sludge well or vacuum receiver is of a certain advantage.

In larger installations the sludge container should be placed at such an elevation that a wagon can be filled independently of the removal of the sludge from the tanks, so that the process may not be unduly prolonged. For this purpose a tower 40 ft. (12 m.) high has been constructed at Mannheim, which holds an iron receptacle having a capacity of 15.7 cu. yds. (12 cbm.). The Frankfort plant has two receptacles for sludge removal standing side-by-side (Fig. 28).

It is possible, also, to provide pits for the temporary storage of sludge, especially when it is removed by the management of the plant, as the process need not then be interrupted in case there should happen to be no field prepared for its reception.

As a large amount of water must be carried as useless ballast in this way it is only practicable for short hauls and small areas.

Where several parties take the sludge regularly the second method is preferable, and a system of piping or channels should be laid for its distribution. Open channels or gutters can only be employed when the land on which sludge is to be applied lies much lower than the plant. Particles of sludge frequently lodge in the channels and putrefy.

Underground pipe systems with branches rising to the surface at suitable points and closed with valves or blank flanges are

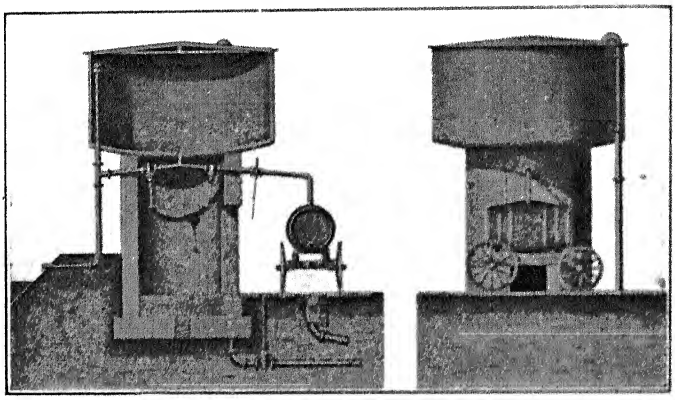

FIG. 28—Sludge Holders (*Frankfort.*)

always to be preferred. Movable lines of pipe can be laid on the surface from these, by which the sludge can be spread over the entire field.

In Mannheim, where nearly all the sludge is thus utilized on a tract of land of about 740 acres (300 ha.), the underground pipes, which are about 1.25 miles (2 km.) long, and are laid in ground owned by the city, are of iron and of 5.85 in. (150 mm.) inside diameter. The sludge is then carried to private lands in surface pipes which also serve for a further distribution on the city fields. These are made of old boiler tubes 3.9 in. (100 mm.) diameter inside, with flanged ends. Where these are to remain for a long time, however, they are furnished with screw joints. A loose joint is sufficient for the distributing pipes as the oozing sludge dries rapidly and closes the joints sufficiently. The pipes can be easily shifted by two men with short iron rakes and drawn together. (Fig. 29.)

The sludge is propelled onward by means of a piston pump. Provision should be made here for forcing water into the pipes to flush them out. This may be found particularly necessary when branch pipes have been long out of use, so that the sludge remaining in them has become thick. Such obstructions can always be removed by flushing. As the pressure can always be increased at option with a piston pump, and also reduced in case of a break in the pipes, this is better adapted for use with a long line of pipe than compressed air from a receiver. The natural hydrostatic pressure from elevated sludge tanks can only be used

Fig. 29.—Sludge distribution pipes. (*Mannheim.*)

where there are also means for increasing this pressure by connecting the distributing pipes directly with the pump or with a compressed air receiver when an obstruction occurs in the system. In general, interruption of operation seldom occurs, but the use of such alternate appliances should be availed of more frequently, especially if the land suitable for drying beds lies at some distance from the plant.

If sludge is to be removed promptly from the tanks a larger sludge well should be provided so that the machinery for its propulsion may be of smaller size, and so that the operation may extend over a longer period.

The largest plant of this kind is at Birmingham. The distance propelled here is about 3.5 miles (5 to 6 km.), and masonry manholes are built for connecting the distributing pipes.

Sludge can be distributed in various ways on the fields. A

method much in vogue in England is to dig ditches from 20 to 36 in. (0.5 to 0.9 m.) wide and 12 to 20 in. (0.3 to 0.5 m.) deep at a distance of about 5 ft. (1.5 m.) apart. (Fig. 30.) After one or two months, when the soil is dried out, these are filled with sludge and, after a few days, in order to prevent objectionable odors, covered to a depth of 2 to 3 in. (5 to 8 cm.) with the earth which has been excavated and placed upon the intermediate strips. This is repeated if the sludge should soak through the covering in wet weather. The land is cultivated for one or two years, after which a new series of trenches is excavated on the intermediate strips and utilized in the same way. A piece of

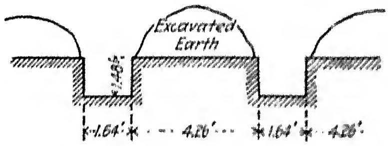

FIG. 30.—Sludge trenches.

land is usually taken of such size that the accumulated sludge of a year can be cared for. Sometimes the second application is made in connection with the first. It is then wise to let the land lie fallow for a year before putting it under cultivation.

As the sludge is buried in thick layers and is withdrawn from the influence of the sun and wind by the covering of earth, it dries slowly. Sometimes, as an experiment, it has been buried deeper. It was found years later, however, in the same condition in the ground and without having decomposed.

Foul odors cannot be avoided with certainty even with the earth covering or the addition of lime. Above all, digging the ditches is costly. In Manchester, with wages of 10.7 cts. (45 M.) per hour, it costs 6.95 cts. per gallon per foot (0.25 M. per l. per m.) with a depth of 15 in. (0.45 m.).

This method has therefore been abandoned in Birmingham in favor of that of placing the sludge on the fields without any special preparation, as this plan has been found satisfactory at Mannheim and Frankfort-on-the-Main. Here about 73,000 cu. yds. (56,000 cbm.) of liquid sludge was utilized in this way during the year 1902. Another method has now replaced it, however, in connection with an incineration plant for rubbish which has been installed recently.

The whole process consists in irrigating the land with sludge.

(Fig. 29.) By making a suitable choice of the crop to be fertilized sludge may be disposed of the year around, without having any large plots lying idle. In Mannheim sludge is placed on sugar beets and tobacco in the late spring until the end of May, after the fields have been sludged in the winter and before the time for planting the summer grain and green fodder. By the end of July it can again be brought to the fields of stubble. In this way the land lies idle but two months.

In order to regulate the operation it is necessary that the tenants, if the lands belong to the city, guarantee to take the sludge at certain times, or agree among themselves at what times it shall be taken. It should be left to the farmers to decide which fields should receive the sludge.

About 160 cu. yds. (120 cbm.) per day with 91 per cent. moisture is given away in Mannheim, while only 47.6 cts. (2 M.) is charged per day for the use of the pipes, besides the wages of the workmen who lay the pipes and apportion the sludge. This returns an income of $428 (1800 M.). An attempt is also made to derive a profit from the sludge, as the 123.5 acres (50 ha.) of municipal land has risen in rental value from $8.70 to $12.50 per acre (90 M. to 130 M. per ha.)—about 50 per cent., so that quite a sum is realized to cover the cost of purification. This shows how the method is employed by the farmers. A comparison of the crops raised on irrigated and non-irrigated land also shows the advantages derived.

The same favorable results have been obtained at Birmingham. Formerly 26 men were employed to bury about 520 cu. yds. (400 cbm.) of sludge daily, while now only 6 men are needed to spread it on the land. This is also shown by the cost. In the first case the cost, including pumping, sinking fund and interest charges and rent for the land, was 7 cts. per ton (0.33 M. per long ton) of sludge, in Manchester even 12.3 cts. per ton (0.58 M. per long ton), while the other process cost but 2.5 cts. per ton (0.12 M. per long ton).

The amount of land required, according to experience in Mannheim, was about 1.9 acres per cubic yard (1 ha. per cbm.) of average sludge received per day. This corresponds to a depth of about 1.45 in. (3.7 cm.) of sludge per year, or a requirement of fully 25 sq. yds. per cubic yard (27 qm. per cbm.) of sludge per year.

In England, where it is of less value for use in agriculture

than its cost, an accumulation of 10 in. (25 cm.) per year is estimated on land having favorable soil, equivalent to an area of 3.6 sq. yds. per cubic yard (4 qm. per cbm.) of sludge. With a heavy clay soil this is increased to 10.8 sq. yds. per cubic yard (12 qm. per cbm.) of sludge or more, and with a medium soil, 7.2 sq. yds. per cubic yard (8 qm. per cbm.) of sludge.

This small area of land is partly accounted for by the favorable climate of England, particularly in winter.

With a quantity of sludge amounting to 19.8 cu. yds. per million gallons (4 l. per cbm.) of sewage and a daily water consumption of 40 gallons (150 l.) per capita, we have 286 cu. yds. per 1000 $\left(\frac{0.150\times4\times365}{1000}=0.219\right.$ cbm. per capita) of sludge per year, and therefore with 10 in. (25 cm.) depth of sludge, about 1.2 sq. yds. (1 qm.) per inhabitant.

As the land is only spread with sludge once in 2 or 3 years the above values should be doubled or trebled, thus approaching the Mannheim value, which was estimated for a yearly application.

The estimates of Schiele ("Mitteil. d. Kgl. Versuchsanstalt," No. 11) of 0.48 sq. yds. (0.4 qm.) per capita seem rather low in comparison.

The same areas are needed for ditches as for irrigation. This method is used in England more for drying sludge than for agricultural purposes.

Low embankments are sometimes thrown up by a plough, therefore, on level tracts of land, forming shallow ponds which are filled with sludge 4 to 6 in. (10 to 15 cm.) deep, and this is dug under when dry. If the land is used in this way several times in succession it becomes more impervious and drying takes a correspondingly longer time. In this case it is better to provide specially drained drying places and to remove the sludge after it has been dried.

If the sludge is used in small quantities on land which is devoted to agricultural uses, it decomposes entirely and the ground is always ready to take up more material. As the sludge only covers the ground in a thin layer (see Fig. 29) it dries rapidly and can be harrowed under without delay. The land does not have to be absolutely level if care is taken to irrigate all parts by the aid of manual labor, and to see that the pipes are properly laid.

By having long sludge pipes (see Birmingham) a sufficiently

large area of land can generally be reached. Sandy soil is especially well adapted for this, as the sludge dries out more quickly. It can, however, stand larger doses of sludge if it is under cultivation. Land which is subject to overflow by streams and cannot be cultivated may be advantageously employed in irrigation. (Mannheim). Provision for under-drainage is not necessary.

This method should be considered where there is septic sludge or fine sludge which cannot be de-watered by pressing or centrifuging, and where drying beds cannot be provided. The former variety of sludge is not very useful in agriculture, but it is quickly disposed of.

Much grease is undesirable, but it disintegrates more readily and harms the field less when spread in thin layers than if in large masses and lumps.

2. Utilization of De-watered Sludge as Fertilizer

The volume of sludge is reduced to one-fourth or more by de-watering to 60 or 70 per cent., thus rendering its transportation for long distances profitable.

In Frankfort-on-the-Main sludge dried in the air was transported as far as 5 miles (8 km.)—in Neustadt O.-S. even 6.85 miles (11 km.) by wagon, and in the latter case 62 cts. per cubic yard (3.40 M. per cbm.) was paid when no lime had been added, or 44 cts. (2.40 M.) with lime. In 1901, $916.30 (3850 M.) was realized from the sludge.

Conditions are seldom so favorable, however. The character of the soil in that vicinity and the production of fertilizer for agricultural purposes have had considerable influence. It is, also, often advisable to give the sludge away to promote its introduction and for experimental purposes.

In most cases a very small price is paid for dried sludge, which is quite out of proportion to the cost of drying, especially when this is accomplished by presses or centrifugal machines. Detritus from screens always brings the highest price on account of its excellent quality. In Torgau 48 cts. (2 M.) per load is paid, in Leipzig 36 cts. (1.50 M.). In the same place 6 cts. (0.25 M.) was paid for tank sludge by lessees of the city, by others 12 cts. (0.50 M.) which was reduced by 6 cts. (0.25 M.) charges for loading. In 1908 the gross revenue was $318.68 (1339 M.) when

there was a great demand, while the cost in wages for removing the dried sludge from the pits was about $6854 (28,800 M.). In Unna septic sludge brings 36 cts. (1.50 M.) per load, in Recklinghausen 9 cts. per cubic yard (0.50 M. per cbm.). This price is frequently obtained, rising sometimes to 18 cts. per cubic yard (1 M. per cbm.).

In general better prices can be obtained in small places than in large cities, as the small farmers, who are the principal users of sludge, are found there in comparatively greater numbers. Large plants are glad to get rid of sludge in any way and to have it called for, to avoid the costs of transportation.

In England they sometimes obtain 18 cts. per cubic yard (1.0 M. per cbm.) for pressed cake, but 9 to 13 1/2 cts. (0.50 to 0.75 M. per cbm.) is often paid to have it carried away.

The sludge is spread on the land and dug under as in the case of manure. The loose consistency of centrifuged sludge renders it easy to handle. The freezing of sludge spread on the fields, which is common when ponded, promotes its decomposition and enhances its fertilizing power.

Half dried sludge can be frozen in cold localities, making it easier to load and transport. The thawing at the places for drying, however, entails more work.

Detritus from screens, possibly also from grit chambers, is often composted with street sweepings, sifted dust, and, in smaller quantities, with dried leaves or pieces of peat, to increase its fertilizing qualities. This is best accomplished in walled pits, in which they are placed in rotation in thin layers. The odors are less with the small surface exposed than if placed in heaps, and when the pit is full can be lessened by the application of a layer of peat. In Cologne 4 pits with a capacity of 130 cu. yds. (100 cbm.) each are used for this purpose.

Wet sludge is also mixed with dust or street sweepings to obtain a material that is more easily handled, and in Cassel, for example, tanks were arranged with embankments of street sweepings, into which liquid sludge was pumped. Masses of the sweepings from the sides were then gradually mixed with the sludge until equalling half its volume. In half a year a material capable of transportation was obtained with 45 per cent. of moisture, having the odor of garden compost, which was given away free. One and seven-tenths pounds of lime per cubic yard (1 kg. per cbm.) was added to prevent foul odors and flies,

but this was not entirely successful. The fertilizing value was also reduced and the cost increased.

It is not advisable to compost wet tank sludge with street sweepings, as this is only possible by forming great heaps, which delays the drying and increases the foul odors. Sweepings, moreover, are more easily cared for by themselves.

3. Production of Fertilizer which can be Strewn over the Ground

Many experiments have been made to secure a fertilizer that can be strewn after drying the sludge to 10 or 20 per cent. moisture, such as has been obtained in the form of poudrette from fecal matter.

They have almost all failed because of the great cost required for artificial drying.

The process is made cheaper by spreading the de-watered sludge in thin layers under cover, rolling it several times or raking it over. In summer the contained water can be reduced to from 10 to 20 per cent. This method can only be used for small quantities on account of the space required, and cannot be employed in damp weather.

With larger quantities the de-watered sludge can be formed into briquettes and dried in the air under sheds, like bricks, as described in the last section.

In either case it can be ground up, producing a fertilizer that can be strewn.

This method requires a prolonged handling of the sludge. The workmen come into contact with it, also, and it remains piled up a long time, although it is not very offensive.

This process is considerably accelerated by the artificial drying already mentioned. Extensive experiments have been made in Frankfort with an apparatus constructed by Fellner and Ziegler, in Bockenheim.

Water is drawn off from the sludge, which has been placed in a rotary drum, filled with iron balls, at a temperature of from 212° to 248° F. (100° to 120° C.) and at the same time the dried mass is ground. The fertilizer which, with a water content of from 5 to 15 per cent. can then be strewn, contains 1.8 per cent. of nitrogen and 1.9 per cent of phosphoric acid. The whole contains, on an average, 47.5 per cent. of organic matter.

From 0.388 cu. yds. (296 l.) of sludge with 72 per cent. water (specific gravity = 1.15) there were obtained hourly 209 lbs. (95 kg.) of poudrette, while 101 lbs. (46 kg.) of coal was used. From this we have the unfavorable factor for the production of steam: $\frac{100\times 101}{388\times 1.15\times 72}=\text{about } 314 \left(\frac{100\times 46}{2.96\times 1.15\times 72}=\text{about } \frac{1}{5.1}\right)$. The large consumption of coal brought the cost of a ton of poudrette to $6.48 (3 M. per 100 kg.) which was much higher than the price for which it could be sold.

The nuisance produced by the foul-smelling gases resulting from the drying could not be entirely prevented, even by conducting the gases under the fire.

The same experience was had in Potsdam, where similar experiments were carried on in the further drying of lignite sludge to secure a more perfect incineration.

Nor has the result sought been reached in the attempt to secure a product that can be strewn by drying between hot cylinders, pressed sludge containing an addition of lime.

In England, on the contrary, very successful methods have been devised for securing a fertilizer that will find a market, as Schiele reports in No. 11 of Mitteilung der Königlichen Versuchsanstalt.

In Kingston the sludge obtained from the A. B. C. process is pressed and then artificially dried and screened. After further drying in the air during storage it is sold as "Native Guano," especially as a fertilizer for flowers, at a price beyond its true value. In spite of this the clarification and further treatment cost about 40 1/2 cts. (1.70 M.) per capita per year. But the employment of a cheaper method of clarification combined with a discharge to the sea would be yet more expensive.

In Glasgow the "Globe Fertilizer" is produced in a similar manner by clarifying with lime and sulphate of iron and then artificially drying the pressed sludge at a temperature of 149° to 158° F. (65° to 70° C.). In 5 years 1.23 million tons (1.1 million long tons) of sludge with 91 per cent. moisture produced 198,000 tons (177,000 long tons) of pressed cake and 6400 tons (5700 long tons) of fertilizer. The former cost 42 1/2 cts per ton (2 M. per long ton) and was sold for from 14.9 to 21.2 cts. per ton (0.70 to 1.00 M. per long ton); the latter, while costing $2.12 per ton (10 M. per long ton) to produce, sold for from $1.70 to $2.12, or in sacks $2.97 per ton (8 to 10 M. and 14 M.

per long ton). This return reduced the cost of clarification by 81 cts. per million gallons (0.9 M. per 1000 cbm.) of sewage. In spite of the smaller price the sale of the pressed cakes was preferred, as they required less work.

No great profit can be looked for by further treatment of the fertilizer, especially as the valuable artificial fertilizers at their cheap prices are always preferred. Even with artificial drying it is a long drawn out process, requiring troublesome manipulation. It is always to the interest of the plant to render the process as short and simple as possible, especially where no great profit can be realized.

b. Complete Utilization of Calorific Value by Burning

A means frequently employed to remove valueless refuse which, when accumulated, becomes offensive from its gradual decomposition and, also, takes up too much room, is by burning. By using the proper apparatus the heat from the gas generated can be utilized, or if this is not done the volume is at least reduced and the final product is an unobjectionable heap of ashes.

The possibility of burning, and especially of utilizing, the calorific value of sludge depends on several conditions which are of great importance, the disregard of which has led to many failures. We will therefore consider them somewhat more in detail.

The degree to which sludge can be disposed of by making use of its calorific value depends upon the proportion of organic matter contained, on the water and on the grease.

The effective thermal value of any material is the number of heat units developed by the combustion of one pound (or of 1 kg.) of the fuel under consideration.

The larger the proportion of organic constituents in sludge the greater the amount of available heat which is released by combustion. The inorganic material and the water contained in it absorb a certain part of the heat generated in raising their own temperature. Water consumes a large part of it, not only because it constitutes a great proportion of the whole, but particularly because it must be converted into steam. 180 b. t. u. per pound are required to raise water from 32° F. to 212° F. (100 calories per kg. from 0° to 100° C.), but to convert water at 212° F. (100° C.) into steam of the same temperature there are required

965 b. t. u. per pound (536 calories per kg.), altogether about 1152 b. t. u. per pound (640 calories per kg.).

As in ordinary incineration plants only the amount of heat can be utilized comprised between the temperature of combustion and that of the gases discharged, and as this last temperature is usually above 212° F. (100° C.), the water contained in the fuel is, as a rule, converted into steam. The heat used in this process is, however, lost, except for a part which appears in the higher temperature of the gases given off.

The effect of the moisture on the burning can be shown mathematically.

The absolute caloric value of the dried material is about 7200 b. t. u. per pound (4000 calories per kg.). With a water content of 90 per cent. there will be 90 lbs. (or kg.) of water in 100 lbs. (or kg.) of sludge. To convert this into steam requires $90 \times 1152 = 103,680$ b. t. u. ($90 \times 640 = 57,600$ calories). The calorific value of the dried material is $10 \times 7200 = 72,000$ b. t. u. ($10 \times 4000 = 40,000$ calories).

Sludge containing so much water has therefore no practical heating value. It is only when it is further dried that we obtain from the calorific value of the material an excess of heat above that used up in the generation of steam. The following table by Koschmieder (Tech. Gemeindeblatt, seventh year) shows to what degree this occurs through the reduction of the contained moisture by 10 per cent.

	With 10 lbs. of dried material			With 10 kg. of dried material		
	B.t.u. = 10 × 7200 = 72,000			Calories = 10 × 4000 = 40,000		
Per cent. moisture	Water lbs.	To convert to steam requires b.t.u. (about)	Resulting excess of heat b.t.u. (about)	Water kg.	To convert to steam requires calories (about)	Resulting excess of heat in calories
90	40	103,680	−31,680	90	57,600	−17,600
80	40	46,080	+25,920	40	25,600	+14,400
70	23.3	26,842	+45,158	23.3	14,912	+25,088
60	15	17,280	+54,720	15	9,600	+30,400
50	10	11,520	+60,480	10	6,400	+33,606
40	6.7	7,718	+64,282	6.7	4,288	+35,712
30	4.3	4,954	+67,046	4.3	2,752	+37,248
20	2.5	2,880	+69,120	2.5	1,600	+38,400
10	1.1	1,267	+70,733	1.1	704	+39,296

Sludge has a practical calorific value only after the contained moisture has been reduced to 80 per cent. This value increases gradually in proportion to the decreasing amount of water to be driven off at decreasing intervals of 10 per cent. (See Chapter IV.) It appears, therefore, that little will be gained by drying it beyond 50 or 60 per cent.

It should also be noted that the temperature must not be lowered below the degree required for combustion when material to be burned is added.

The grease contained is a disadvantage in burning inasmuch as this must be distilled off at a temperature of 572° F. (300° C.) before reaching the temperature of combustion. The heat thus used is lost, as these distilled vapors are not consumed in any ordinary furnace. With every addition of material to be burned, therefore, the moisture must be turned into steam, the grease and similar substances must be distilled off, and it is only with a yet higher temperature that we obtain gases of the degree of heat required for practical use.

When burning dried sludge in house stoves the grease is distilled off and is quickly deposited on the cooler parts of the heating apparatus, resulting in much dirt and the production of impure gases which escape into the room and render the air impure. When it is burned under steam boilers the gases escaping through the chimney annoy the people of the neighborhood.

Although we find from the above that sludge sufficiently dried can be burned without adding other material, its use is too limited to make further drying, except by the usual methods, of economic value. Experiments in this direction have, however, been made.

In Frankfort-on-the-Main briquettes made from de-watered sludge with brick presses and dried in the air to 10 per cent. of moisture gave an effective calorific value of 9910 b. t. u. (2500 calories), on an average with 47 per cent. of combustible material.

According to Bredtschneider and Proskauer (Vierteljahresschrift f. öff. Ges.—Pflege., Vol. XXXVII) air-dried sludge with 20 per cent. moisture contains about 30 per cent. combustible material and about 50 per cent. mineral matter, and has a calorific value of 8730 b. t. u. (2200 calories).

Experiments at Elberfeld have shown that sludge with as much as 60 per cent. moisture can be burned without the addition of coal by using a forced draft.

As valuable combustible materials, such as carbonic acid and

methane, are lost during decomposition, sludge from septic tanks is less suitable for heating purposes. In Stuttgart the calorific value of septic sludge with 40 per cent. moisture was 6456 b. t. u. (1627 calories); with settled sludge containing 47 per cent. moisture, 8035 b. t. u. (2025 calories). In comparison we have: lignite sludge from Potsdam with 60 per cent. moisture, 5950 b. t. u. (1500 calories), and settled sludge from Hanover, dried at 212° F. (100° C.), 15,870 b. t. u. (4000 calories), with 28 per cent. ash and 17,120 b. t. u. (4315 calories), with 18.5 per cent. ash. A certain increase in calorific value is found in coal mining districts due to particles of coal in the sewage.

Coal or other combustible material, such as dust, has been mixed with sludge to increase its calorific value in order to render its use practicable. The coal can be added to the sewage, to the wet sludge or to the dried sludge before it is used.

The first method brings out the most economical use of the material added. It can be used as a means for clarification, as in the lignite process. The addition of coal or peat also facilitates drying in the air as well as by pressure, and retards the decomposition of deposited sludge. If the material that is to be burned is mixed with wet sludge, this is best in the form of coal dust, which is thoroughly incorporated with the sludge by a process patented by the firm of Rothe, in which it is sucked in like porridge through a lateral suction pipe in the sludge pump.

The complete utilization of the calorific value is, therefore, the approved practice in using the lignite process, and as Reichle and Dost have shown by experiments to be described later, the foul material contributes from 11 to 30 per cent. of the resulting calorific value.

Experiments at Charlottenburg, where sludge containing 40 per cent. moisture was burned with the addition of coal, more coal was required to obtain a certain amount of steam than if coal alone had been used. For other reasons, too, stress should be laid upon mixing as thoroughly as possible.

In the lignite process, where 4.1 to 8.3 tons per million gallons (1 to 2 kg. per cbm.) of ground lignite with alum and sulphate of iron are added to the sewage, the sludge is usually burned under the boilers of the apparatus just as it comes from the press. If it is received in the consistency of gruel, which cannot always be avoided with its variable character, other sludge which has received additional drying in the air under cover is mixed with it.

The grate is supplied with diagonal bars. The resulting ash is about 1/7 of the original amount.

In Cöpenick the lignite sludge which has been dried in tanks three or four weeks, is heaped up under cover for about four months, and this high piling up has been found of greater advantage than placing it in thin layers, so that the large drying sheds have been but partially used. The calorific value with about 40 per cent. moisture is 8630 b. t. u. (2175 calories). It is burned in the neighboring electric plant with an addition of one part of coal to 2 to 4 parts of sludge, applying, at the same time, a forced draft. Lignite sludge is also used at Potsdam in the municipal electric plant, but without previous storage, using a mixture of 1 part coal slack to 8 parts sludge. The electric plant, which uses no other fuel, pays therefor $2142 (9000 M.), which represents only a part of the cost of the sludge.

An experimental plant of the Nuremberg Machine Manufacturing Co., Inc., dries the wet lignite sludge by heat, the final product —a firm black mass—is used for fuel and the steam generated thereby employed to operate the machinery. Further particulars as to the success of this plant cannot yet be given.

At Spandau the lignite sludge is made into briquettes and sold at $1.52 per ton (0.70 M. per 100 kg.) for fuel. In other places the sludge briquettes which are not needed to operate the clarification plant are given away to poor families.

Experiments with septic sludge from Emscher tanks show that it burns when containing 46.4 per cent. moisture with an addition of from 20 to 5 per cent. of coal, when 50 per cent. which has no commercial use is left as ash.

Besides the complete utilization of the calorific value, an attempt should be made to secure an ash having value, on account of its large amount. This is especially worthy of attention where there is a lack of sand and gravel for mortar and concrete. At Huddersfield, England, the pressed sludge from chemical precipitation is mixed with coke breeze in the proportion of 5:1 and burned. The resulting slag is used with lime and cement to make mortar. The operation is expensive, however, the burning alone costing, in the added coke and wages, 55.2 cts. per ton (2.60 M. per long ton), to which should be added 53.1 cts. per ton (2.50 M. per long ton) for pressing. The only advantage lies in the fact that the entire product is thus utilized without any waste.

This point is not worth considering in lignite clarification plants

where the residue of ash is but 1/7 of the whole amount. The complete utilization of the calorific value is of importance in reducing the high cost of the process, especially as large machines are necessary to do the work.

It has even been proposed to lessen the burden on the sewage at Berlin by clarifying a part of the sewage with coal and then utilizing the sludge in the production of electrical energy for the railways. With an addition of from 20 to 30 per cent. of lignite there has been estimated a return of 21,431,000 k. w. h. from 164,640 tons (147,000 long tons) of sludge.

Centrifuged sludge is particularly well adapted to burning on account of its loose consistency. A separate extraction of grease from the sewage in order to produce a sludge without this ingredient is of advantage, as has been already explained in the remarks on combustion.

In Bradford, where all the sludge is worked over for the grease, the pressed cakes without grease are mixed with coal in the proportion of 7:1, while a heated forced draft is used to prevent any annoyance from smoke, and the cakes are then burned under steam boilers, thus saving an annual expense of $4760 (20,000 M.) for fuel.

Briquettes made from sludge dried to 75 per cent., with coal and bitumen added, have been used for fuel in Columbus, U. S., but as in all experiments with a mixture of more valuable fuel, the cost has been greater than its actual value.

The incineration of sludge with dust or street sweepings combined, has frequently been found practicable, the most notable example being at Frankfort-on-the-Main, where centrifuge-dried sludge has been treated in this way. Experiments there indicated that sludge with 75 per cent. moisture mixed with house sweepings would burn without any additional fuel; so, also, in Charlottenburg where, with a mixture of 1 part sludge with 75 per cent. moisture and 3 parts house sweepings, 1 lb. evaporated from 0.76 to 1.08 lbs. (1 kg. evaporated 0.76 to 1.08 kg.) of water in the boiler.

This method is frequently used in England where pressed cakes containing 50 to 60 per cent. moisture are customarily mixed with dust in the proportion of 1 to 2. The calorific value of the material is utilized to operate the plant. This is, naturally, not great. In Bury 67 to 78 tons (60 to 70 long tons) of the mixed material are burned daily, furnishing 38 h. p. for

the engine boilers of the plant. The slag resulting from this method can be melted and ground. It is then used for building material. Especial attention is given to the gases produced, as these may easily cause annoyance.

c. Production of Gas

The unfavorable results obtained in utilizing the combustible material in sludge as fuel which have been described have led to experiments by which its calorific value may be more fully realized through its conversion into gas.

A distinction should be made here between the removal (entgasung) of the gas and the production (vergasung) of the gas from the sludge.

The former is accomplished by driving out the volatile ingredients, especially the carburetted hydrogen, which makes a very valuable gas, by a high temperature. This is dry distillation, such as is employed in making illuminating gas.

By the production of gas is understood the combination of the carbon contained in the material with the oxygen of the air to form carbonic oxide. This can be brought about by passing air through glowing coals. Carbonic oxide gas is produced which, when mixed with the inert nitrogen of the air, is called producer gas. This is not a perfectly combustible product, as the carbon is consumed only to the degree necessary to produce carbonic oxide, but not carbonic acid.

If steam from water is brought into contact with glowing coals the oxygen in it unites with the carbon, forming carbonic oxide, and the hydrogen is set free. The mixture of these two gases is called water gas. In the suction gas producer, air and steam are admitted at the same time and the resulting gas is a mixture of both kinds. These gases are usually mixed with other volatile substances which are freed from the combustible material recently added to the upper layer in the generator.

At first attempts were made to drive off the gas from sludge, but so far this has been without practical success. The reason for failure is the great volume of the water contained in the sludge as compared with the small amount of combustible material, a condition which constitutes the great difficulty in all methods of utilization. A great deal of fuel is required to heat this great mass, while the value of the gases obtained is not

in proportion. Moreover, a considerable amount of r
remains after the gas has been removed.

This is also shown in the experiments undertaken in T
remove the gas from sludge produced by mixing peat wi
sewage of Stuttgart. Here from 1.96 cu. yds. (1.5 cb
sludge weighing 1700 lbs. (770 kg.) there remained a residu
retort of 534 lbs. (242 kg.) = 31.4 per cent.—quite a large a
—and the gas obtained was about 7060 cu. ft. (200 cb
417 cu. ft. from 100 lbs. (26 cbm. from 100 kg.) of sludge
1700 lbs. (770 kg.) of coke. The calorific value of the
obtained was 16,578 b.t.u. (4178 calories) as compare
possibly 19,840 b.t.u. (5000 calories) in the case of illumi
gas, and the cost of production (fuel and wages) $1.27 p
cu. ft. (0.19 M. per cbm.).

The cost of production is therefore very high in propor
its value. The conditions are still less favorable with or
settled sludge, as was shown by experiments at Frankfort-
Main. Here, from 220 lbs. (100 kg.) of air-dried briquett
690 cu. ft. (19.5 cbm.) of gas was obtained. After a
period 50 per cent. residue was found. The gas containe

Hydrogen,	36 per cent.
Carbon,	23 per cent.
Methane,	13 per cent.
Heavy carburetted hydrogen,	6 per cent.
Carbonic acid,	16 per cent.
Nitrogen,	6 per cent.
	100 per cent.

Its calorific value was 15,000 b. t. u. (3800 calorie
maximum 16,860 b. t. u. (4250 calories). The illuminatin
was small, 5.3 candle power while using 5.3 cu. ft. (150
hour, so that the gas cannot be used for lighting.

Similar results were obtained with sludge from septi
and plain sedimentation in Stuttgart, as the following
indicate.

There is, therefore, no question of economy in the pro

Experiments for converting sludge into gas have result
favorably although, even here, there has been no sati
solution.

The same unfavorable characteristics of settled slu

	U. S. measures			Metric measures		
		Septic tanks	Sedimentation tanks		Septic tanks	Sedimentation tanks
Gas obtained per	ton sludge.....	5330 cu. ft.	7700 cu. ft.	100 kg. sludge	16.6 cbm.	24 cbm.
Cost of production per.....	cu. yd. sludge.	6.6 cts.	7.7 cts.	cbm. sludge...	0.36 M.	0.42 M.
Cost of converting into gas per	cu. yd. sludge.	$6.55	$9.10	cbm. sludge...	36.00 M.	50.00 M.
Max. calorific value per....	1000 cu. ft. gas.	363,800 b. t. u.	378,200 b. t. u.	cbm. gas......	3242 cal.	3371 cal.

shown here as were found in connection with burning, as might be expected, for both processes aim to secure its entire calorific value.

Gas obtained is used to drive engines. As the calorific value of the sludge is small these engines must be made very large. Besides, the preliminary distillation of the grease, which quickly condenses, makes the engine and plant for the production of gas very dirty, so that ample reserve must be provided for uninterrupted power.

The heat required to convert the water into steam and distill the grease might be recovered by passing their vapors over glowing coals, possibly by admitting them into the fire box, thereby inducing further decomposition. In using wet sludge for making water gas the method suggested by Koschmieder may be employed: of conveying the steam from the sludge to the generator, thus utilizing the heat devoted to that purpose. The heat from the gases may be used to further dry the de-watered sludge. Coal to the amount of 1 1/2 times the wet sludge should then be added. This increases the cost of the process, and probably in a greater degree than by special drying of the sludge or by other processes where the storage or prolonged treatment of the sludge is avoided.

Sludge which has not had coal added during or after clarification is not suited to the removal of gas.

The experiments which have been made in this direction by the Deutz Gas Engine Works have therefore only dealt with coal-clarified sludge. Of these experiments, some of which were undertaken at Deutz, some at the Dresden Municipal Exhibition and some at the experimental plant at Oberschöneweide, we will only consider those made by Reichle and Dost at the last-named place, as the results are all similar.

The experimental plant, which has now been abandoned, consisted of a generator, a condensing plant, and a suction gas engine of 70 h. p. With an addition of from 5.63 to 8.23 tons of lignite and from 0.75 to 1.13 tons of sulphate of alumina to 1 million gallons of sewage there were obtained 12.5 tons of sludge (with 1.35 to 1.97 kg. lignite and 0.18 to 0.27 kg. sulphate of alumina per cbm., 3 kg. of sludge) with 64 per cent. moisture having a calorific value of 3202 b. t. u. per pound (1779 calories per kg.). The sludge received from the press with this amount of moisture was dried in the air to 51 per cent., for, as was shown

by these experiments, sludge with 58 per cent. or more cannot be converted into gas.

The following composition was the result of an analysis:

Carbon,	22.3 per cent.
Hydrogen,	2.7 per cent.
Nitrogen,	1.0 per cent.
Oxygen,	12.8 per cent.
Sulphur,	0.5 per cent.
Ash,	9.8 per cent.
Water,	5.1 per cent.

The calorific value of the gases produced was on an average 81,000 (maximum 90,000) b. t. u. per. 1000 cu. ft. of gas, as compared with 146,000 or more with other power gas [721 (maximum 801) calories per cbm. as compared with 1300 or more]. The engine, therefore, only furnished 57 h. p. The amount of lignite sludge was 5.56 lb. (2.52 kg.) per brake horse-power-hour, whence we have a thermal efficiency of $\frac{2510 \times 100}{5.56 \times 3202}\left(\frac{632 \times 100}{2.52 \times 1779}\right)$ $= 14.1$ per cent. 3202 (1779) here represents the calorific value of the sludge and 2510 (632) the heat units required for one h. p. hour.

The impure matter increased the heating value by from 11 to 30 per cent., the sewage being composed mostly of factory wastes without combustible ingredients.

As the cost of fuel is 0.36 to 0.50 cts. (1.5 to 2.0 pfg.) per h. p. hour, and about 15 per cent. of the power derived from the sludge was utilized for the clarification plant, the cost of operation at Oberschöneweide, as was demonstrated in 1905, was reduced from 33.1 cts. to 24.5 cts. (1.39 M. to 1.03 M.) per capita per annum, or by $16.20 per million gallons (1.8 pfg. per cbm.) of sewage, including interest and amortization charges.

Such utilization of lignite sludge has a certain economic advantage which can be increased by improvements as already indicated: The costs of maintenance and operation may be reduced if the process is used in connection with a municipal power plant where sludge is available. It does not seem wise to adopt the lignite process merely for the profitable use of the sludge when its advantages—freedom from odor, small area required, easy handling and therefore the possibility of establishing the plant in populous districts—cannot all be realized.

Recently a plant of this kind, to utilize sludge for power gas, has been installed at Elbing, but although no decided opinion can be expressed after the short time it has been in operation, it does not appear to meet the expectations as to cost.

d. Extraction of Grease.

The grease contained in sludge is detrimental to the methods of utilization hitherto described. In order to realize the greatest possible value either as a fertilizer or for fuel it is necessary to eliminate the grease, or at least to have as little of it as possible. But the contained grease itself represents a valuable product. It is necessary, however, to extract it from the sludge in the simplest and most economical way.

This can be done:

1. By extraction of the grease from the settled sludge.
2. By extraction of the grease from the sewage either by itself or in connection with other materials.

A mechanical separation of the grease by its rising to the surface on account of its light specific gravity does not take place in connection with sludge as it is too intimately mixed with the particles of the latter. In de-watering by centrifugal force in closed drums the grease separates from the water in the center and can be collected.

Both of these methods have been tried out in practice.

The first is more generally known in Germany from a plant at Cassel erected by Degener through the Cassel Machine Works—Incorporated, formerly the firm of Beck and Henkel.

The sludge, which was given away by the city of Cassel just as it was obtained, and which contained coarse sedimentary and floating matter on account of the lack of grit chambers or screens, was worked over by the following processes:

1. Freeing the sludge from its coarse ingredients (rags, sticks of wood, etc.) by a rolling screen.
2. Mixing with sulphuric acid in kettles.
3. Heating the mixture in Montejus [3 to each 3.9 cu.yds. (3 cbm.)] to 212° F. (100° C.).
4. Pressing the heated material in filter presses. The drainage water was conveyed to a lime well to neutralize the acids and returned to the plant.
5. Drying the pressed cakes, first by introducing steam into

the presses and thence, after they were disintegrated, into an apparatus heated by steam.

6. Extracting the grease by benzine in an extractor holding 8.5 cu. yds. (6.5 cbm.).

7. Liberating the grease and sediment from the benzine by steam. The latter was recovered by condensation and could be used again several times.

8. Subsequent drying of the sediment in thin layers in the air or in a drying apparatus after the moisture had been reduced to 40 or 50 per cent. by steam.

9. Distillation of the grease. This produced two layers of grease, yellow and brown, while a tar-like material remained as residue.

The amount of grease extracted varied from 8 to 25 per cent. and averaged 15 per cent. of the dried material in the sludge cakes, while the average amount of grease contained in the sludge was 18 per cent.

The residue, deprived of grease, found a good market as a fertilizer and had the following composition referred to the dried material:

Nitrogen,	2.35 to 5.90 per cent.
Grease,	0.71 to 5.89 per cent.
Phosphoric acid,	0.41 to 1.12 per cent.
Potash,	0.03 to 0.15 per cent.

As shown above, this method was very troublesome. In addition to a good deal of machinery it required 16 men for operation—8 by day and 8 by night.

The final product was unobjectionable from a sanitary point of view and the process was, moreover, harmless for the workmen.

As many alterations and improvements were found necessary in trying out the plant, the capital required had to be increased, making, with the high cost of operation, economical results impossible. After 3 years, therefore, it was abandoned, and the contract with the city of Cassel was cancelled.

The principal reason for the high cost of operation was the great expense that had to be incurred for fuel used in heating the wet sludge and in drying the pressed cakes, which was out of proportion to the value of the grease contained (See page 10).

Experiments made at Frankfort-on-the-Main to extract grease with benzine from wet sludge containing 15 to 20 per cent. of

grease in the dried material showed the process to be uneconomical.

Extracting grease from sewage sludge obtained under normal conditions can never be profitable.

The situation is different in towns where much grease is discharged into the sewage from factories, as, for example, in various English cities from wool washing works.

The largest plant of this kind is at Bradford (Fritzing Hall): 14.53 million gallons (55,000 cbm.) of sewage, half of which comes from wool washing establishments, are treated there daily by the addition of sulphuric acid. The sludge, with 80 per cent. moisture, is heated to 212° F. (100° C.) by steam and then led into hot filter presses, where the grease, which has been separated by the sulphuric acid, is pressed out with the water. The grease separates from the water and is refined. In 1904 it brought a revenue of \$29,300 (123,000 M.), but at a cost of \$59,500 (250,000 M.), for sulphuric acid.

The pressed cakes contain, in addition to from 30 to 40 per cent. of water, from 15 to 25 per cent. of grease, and are used for fuel; for, as has been stated, they are not suitable for use as a fertilizer on account of the grease. In an experimental plant one part of it is worked over for grease by heating the sludge cakes in retorts to 600° F. (315° C.) in order to distill the grease. This is then drawn up by suction and condensed when it is almost as valuable as when first obtained. The gas water obtained is treated for ammonia at the gas plant while the pulverized residue, containing 1.5 per cent. nitrogen, serves as a fertilizer.

If the liquid wastes from wool scouring and cloth finishing plants are treated separately, the grease recovered sometimes pays for the entire cost of purification. It is of advantage to treat the sludge from several factories in one plant.

The great disadvantage in treating large volumes of watery sludge, as at Cassel, especially the heating, may be lessened if the grease is extracted by itself from the main body of the sludge, as is done with the floating layer in the Kremer apparatus. It is impossible to prevent a part of the grease in the bottom layer from being lost, but the value and amount of grease in city sewage is not so great as to make one lay great stress on this fact.

It is much more important to keep the rest of the sludge as free from grease as possible, as it is then more suitable as a fertilizer and for fuel and can more readily be rendered inoffensive by

decomposition. The removal of grease is also of advantage in connection with irrigation and final biological purification.

The layer of grease in the Kremer apparatus, containing an average of 72 per cent. moisture and about 45 per cent. grease in the dried material, is placed in a perforated vessel for further drying, and in small plants can be given directly to soap manufacturers, who are glad to get it. If several places with such arrangements for obtaining the grease from sludge are located near each other, the sludge can be delivered to a single plant for the further extraction of the grease withe tetra-chloride of carbon. With cities of 45,000 inhabitants and upward an independent plant for working over the sludge is warranted.

A thorough extraction of the grease should be aimed at for economical reasons; for, assuming that 16.1 lbs. (7.3 kg) per capita reaches the sewage each year, and that about 15,000,000 people in Germany live in cities having sewers, about 121,000 tons (110,000,000 kg.) of grease are lost annually.

c. Various Other Methods of Disposal

Aside from mixing sludge precipitated by lime with clay to make cement, or settled sludge with loam to bake into bricks (these methods having little economic value on account of the cheap price of good cement and brick, but being, nevertheless, employed to a considerable extent) we will here mention briefly methods for disposing of it without utilization.

Sludge is frequently used, after it has been dried, for filling in land, sometimes with the addition of slag or sand. The residue from grit chambers is particularly adapted to this purpose, as it contains but little organic matter; and, in particular, septic sludge, as it has but little heating or fertilizing value, and is not subject to offensive decomposition. Very greasy sludge can often be used in this way only, as it is very difficult to dry.

Depressions in the ground, abandoned sand or gravel pits, the dry beds of streams or shores of rivers (Elberfeld) are the best dumping grounds.

This method of disposal is much used at Leipzig, where about 163,000 cu. yds (125,000 cbm.) of wet sludge are annually disposed of in sludge beds of about 21 acres (8.5 hec.). By using an old stream bed lagoons are formed by earth embankments, into which the sludge is pumped to a depth of 15 ft. (4.5 m.).

A scum forms on top which at last breaks, sinks, and the liquid rises to the surface. This gradually evaporates, the sludge becomes firmer and after lying for some years is in part carted off.

In the case of cities on the coast the sludge can be carried to sea, as is done in many English cities: London, Manchester, Southampton, Dublin and Glasgow. London, at Barking, has the best arrangement for this. The sludge is there pumped into large sludge tanks, as its removal is sometimes interrupted by fog, and the water rising to the top is drained off. Six steamships having a capacity of 1300 cu. yds. (1000 cbm.) each are used to carry the daily accumulation of about 7800 cu. yds. (6000 cbm.) of sludge to about 50 miles (80 km.) beyond the mouth of the Thames, where, in order that it may be washed further out, it is dumped shortly after low tide.

In other cities vessels with a capacity of from 780 to 1300 cu. yds. (600 to 1000 cbm.) are used, but they do not have to go so far out. At Dublin the sludge is dumped but 2.2 miles (3.5 km.) from shore.

Considered from a sanitary standpoint this method is free from objection as the sludge is at once rendered harmless, but its valuable constituents are lost and the cost of disposal is quite large. Including loading the vessels, interest and sinking fund charges, and harbor taxes, this amounts to:

7.2 cts. per ton (.34 M. per long ton), at Glasgow.
8.9 cts. per ton (.42 M. per long ton), at Dublin.
10.0 cts. per ton (.47 M. per long ton), at London (Barking).
12.3 cts. per ton (.58 M. per long ton), at Manchester.
29.7 cts. per ton (1.40 M. per long ton), at Southampton, wher the removal is done by contract.

Septic sludge is disposed of in a peculiar way at Columbu During high water it is discharged into the Scioto River whic passes the purification plant. The dilution is about 1:80 As it can only be discharged at high stages of the river the sludg remains in the tank through the summer (about 8 months As septic sludge is not offensive no objection can be made this method so long as no deposits accumulate in shallow place It may be adopted near bodies of water in which there is no tide

CHAPTER VI

Considerations Regarding the Treatment and Utilization of Sludge in the Choice of a Method of Clarification

The requirements of the different methods for removing sludge from tanks and drying and utilizing it have already been considered in the separate foregoing chapters, as well as the advantages and disadvantages of these methods.

In order to utilize the product profitably it is necessary in planning the work to give due consideration to the method of treatment and its utilization.

If it is apparent from what has been said heretofore that the processes for the treatment and utilization of sludge have been developed to such an extent that there is no necessity to reduce the degree of purification through apprehension of a troublesome sludge burden; yet the mistakes that have been made due to an insufficient study of the sludge question and an underestimate of its importance can generally be rectified only by a large outlay for improving the mode of operation.

The composition of sludge has, up to this point, been accepted as something definite. If it is not possible for an engineer designing a clarification plant to radically alter the character of the sludge, he can at least modify it to a certain extent in his choice of a method and in perfecting its details, especially those features which are of consequence in and materially facilitate subsequent treatment and utilization.

The necessary degree of clarification is, of course, the fundamental consideration to which the treatment of the sludge must defer. But by measurement of the sludge the solution of the problem can be made easier, if a removal of the foul matter from the sewage be required up to the absolutely necessary degree, depending upon the composition of the water into which it is discharged and special local conditions; for with the reduction of the quantity of sludge the difficulties of disposal will diminish as well as the expense, which is always a hinderance to a hygienically desirable and thorough purification. The more complete the purification the greater the amount of sludge deposited.

After the experience of the past in the utilization of sludge, (and there will be but few important developments in the future) no more foul matter will be separated from the sewage than is demanded for sanitary reasons, without attempting to further increase the volume of utilizable sludge; for it is certain that with city sewage no profit can be secured sufficient to cover the cost of the plant and furnish additional revenue.

The amount of sludge to be looked for should not be underestimated, and it is therefore advisable to assume the maximum values given.

The effort of the designer should be to so arrange the methods and apparatus for removing sludge from tanks, for reducing the water content and for utilization and so to select the method, that the sludge may be rendered harmless according to the demands of sanitation and at the least cost. He should examine carefully into methods to see if something simpler will not lead to the same result, or whether a slight increase in cost may not be more than offset by the avoidance of some complicated process.

It is not possible without much repetition to mention here and describe further all the combinations which follow from considerations of the efficiency of clarification, of the composition of sewage and of special local conditions, such as available room, relation to populous districts of the city, etc. Only a few important points will therefore be emphasized.

The principal aim should be to obtain little sludge; or, what is the same thing, as the amount of dried material to be separated corresponds to the clarification effected, sludge with as little moisture as possible. The reason for this is stated in several places.

If the degree of purity required is high, this should be obtained, not by reducing the velocity in the tanks, but by passing through contact beds or over irrigation fields.

The construction of the tanks and the mechanical appliances for removing sludge during operation should be examined primarily with reference to the amount of water contained in the resulting sludge, and especially where little room is available for drying beds and where the general conditions, as well as the daily volume of sludge, render de-watering by centrifugal machines impracticable, the disadvantages of removing sludge during interruption of operation should, in some cases, be accepted. Digestion of sludge in Emscher tanks may at times be an advan-

tage, especially in small installations, where there is a great saving in labor, as the sludge need not be removed daily and this is easily done. Still simpler is the treatment of sludge in septic tanks of ordinary construction, but other disadvantages, such as the necessity of subsequent cleaning, as well as the storing up of great masses of decomposing matter in the neighborhood of inhabited dwellings, etc., often stand in the way of their use.

Sludge should be obtained in such a condition that it is suitable for drying and subsequent utilization, as well as for removal from the tanks. For this reason it is necessary to free it from grease and cellulose. This is best accomplished, especially with greasy sewage, by the separation of these substances from the sewage. There is economy in recovering the grease from settled greasy sludge. The preliminary separation of the grease is especially desirable in the case of contact beds, sand filters and irrigation fields.

As to drying, which proceeds more rapidly after decomposition and the extraction of grease in the open, the use of remote sludge-drying beds is often to be recommended.

With artificial methods of drying, centrifugal machines seem open to much improvement. Here it is a question of reducing the cost of the apparatus for drying by simplifying the centrifugal machine, of which perhaps the one constructed on the principle of a cream separator might be improved.

De-watering by filter-presses need be considered only in special cases, as, on the one hand, sludge without the admixture of other material is not adapted to this treatment, and on the other, it is not economical to add this merely to secure a sludge capable of pressing, especially as the volume of the sludge is thereby increased.

Many experiments have been made in the utilization of sludge and many processes have never passed beyond the experimental stage, so that it is as yet impossible to judge of them. The author has gone into these experiments with care, as it is only from them that opinions can be drawn as to any possible developments that may reasonably be looked for from the active interest taken in the matter.

From a sanitary standpoint the goal to be aimed at is the quickest possible removal of the sludge and rendering it harmless and this is likewise true regarding its disposal and drying. As this is not possible without expense, economy demands the

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complete utilization of the valuable materials in the sludge to reduce the cost of treatment, or at least the expense of rendering it harmless.

If the first case seldom occurs, as shown in Chapter V, there is a saving in giving the sludge away to farmers who are willing to take it. Using sludge as a fertilizer is the best way to utilize the valuable ingredients, which are constantly increased in amount by the general extension of sewerage. The nitrogen in particular is conserved, for the production of which new sources and processes are being constantly sought, while by burning this is lost. The extraction of grease is always of advantage when used for agricultural purposes.

Irrigation simplifies the treatment of sludge. It should, therefore, always be employed where the conditions render it possible. It answers the same purpose with respect to the utilization and rendering inoffensive of the impure material as does irrigation with sewage, which is the best method as to its removal and utilization.

Incineration as well as the production of gas—which latter process can and will be improved—are the methods of utilization indicated where clarification is brought about by the addition of coal or peat.

The addition of coal to ordinary sludge to facilitate combustion seems advisable in a few cases only, but mixing with house sweepings for the same purpose is to be commended; only, however, in case the sludge cannot be disposed of in some cheaper and simpler way.

Particular emphasis should be laid on the greatest simplicity in the method of utilizing sludge.

Extracting grease, according to the present status of methods employed, can only be done with economy where this is done by itself in connection with particularly greasy sludge.

A brief summary of the principal processes in their relation to the treatment and utilization of sludge is given here. No consideration is given to their various advantages or disadvantages, as has been done generally in this treatise.

The points considered are:

a. Composition and amount of sludge.
b. Methods of removing sludge.
c. Adaptability of sludge to drying.
d. Possibility of the utilization of sludge.

In this brief space the various modifications of method, which are very great in sedimentation processes, cannot be treated. The reader is referred to Chapters III and IV.

1. Grit Chambers.

a. Small amount; composition and moisture contained, dependent on design and operation, in general favorable.

b. Removal of sludge, with and without interruption, without foul odors.

c. Special arrangements for de-watering unnecessary.

d. Very little value, chiefly for filling land.

2. Mesh and bar screens.

a. Small amount and little moisture. Putrescible.

b. Simple separation in fresh condition.

c. Special arrangements for de-watering unnecessary.

d. Good sale as a comparatively valuable fertilizer.

3. Sedimentation in Tanks and Wells.

a. Large volume and much moisture, especially with wells and tanks where removal occurs during operation. Very putrescible.

b. Removal of sludge favorable or unfavorable, according to the special construction. In tanks, usually with interruption of operation and foul odors; in wells more favorable but with larger volumes.

c. Large plant for drying necessary, as sludge is not always of favorable character. Foul odors only avoided by mechanical apparatus.

d. Useful as a fertilizer, but less so than from screens and less readily disposed of on account of the large volume.

4. Chemical Precipitation.

a. Very large volume. Not very putrescible.

b. As in the case of 3b, but with less odor.

c. De-watering practicable, also in filter-presses; little nuisance from odors.

d. Of very little use.

5. Lignite process.

a. Very large volume with much moisture. Not putrescible.

b. Removal during operation without foul odors.

c. De-watering in filter-presses or in the air quickly and without odor.

d. May be utilized by burning or conversion into gas.

6. Septic tank process.

a. Small volume. Little moisture. Non-putrescible.

b. Little nuisance from odor, depending upon the method of removal. Interruption of operation.

c. Favorable consistency for drying.

d. Slight utility, as calorific and fertilizing values are reduced.

7. Emscher Tanks.

a. As with 6a.

b. Removal during operation without foul odors.

c. As with 6c.

d. As with 6d.

8. Kremer Apparatus.

a. As with 3a, but more favorable composition due to the extraction of grease.

b. Removal during operation, when sludge with less moisture than with 3b is obtained, on account of the absence of grease.

c. For the same reason, favorable consistency for de-watering.

d. Greasy sludge favorable for the extraction of grease; sludge at the bottom, on account of little grease, more favorable for fertilizer than ordinary settled sludge.

Biological treatment, intermittent filtration and irrigation are omitted, as they have been in the entire treatise, because sludge here plays an unimportant rôle and its treatment depends entirely upon local conditions and the method of operation.

Concluding Remarks

There are many methods for the treatment and utilization of sludge and it would be a mistake to set up any one method as best, for each has its advantages and each its faults, and these have weights varying with the local conditions. Certain characteristics and arrangements may prove of great disadvantage in a large city while well adapted to a small town, and *vice versa*.

The choice must be made to suit the local conditions and in any given case these must make necessary corresponding modifications of plan.

If this is not observed we have the case so often met with of a method adapted to one place and working admirably, failing entirely at another. The blame is then usually laid—and partly with reason—to an overestimation of the special invention; for it is frequently observed that inventions otherwise useful and the results of experiment lose their value by being generalized, and naturally are not carried out under the same conditions.

The best solution of the sludge question can only be found by study of the individual case, and firmer foundations laid by further experiment and the practical application of the various methods.

A sanitary and economical treatment and utilization of sludge is of importance for each plant, and one can but agree with Metzger when he concludes his report on this question at the International Congress for Hygiene and Demography at Berlin in 1907 with the sentence: "The treatment and utilization of sludge are of such great importance that no plant should be completed until all the questions of subsequent treatment have been finally answered and settled by avoiding the conditions known in principle to be evil."

THE DRYING OF SLUDGE

A Report from the Sewerage Division of the Emscher Association. Kgl. Baurat Middeldorf, Chief Engineer. Dr. Ing. Imhoff, Division Superintendent.

BY

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ESSEN-RUHR

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INTRODUCTION

The Sludge Question.—The difficulties encountered to-day in treating sludge lie less in the methods employed than in the characteristics of the sludge. The liquid masses of sludge obtained from sewage can neither be utilized nor left at the plant, and, as a rule, cannot be removed without great cost.

In England, where the question of sewage purification was first considered on a large scale, on account of the small volumes of water available into which it could be discharged, and where every large city has its disposal plant, the sludge question has become most urgent. The editor of *The Surveyor* has recently said:[1]

"The solution of the sludge problem is the most pressing question of the day and a little practical assistance in this direction from our scientists would be of much greater value than all the learned dissertations on theories and doctrines with which we have been favored in recent years."

The well-known authority, Barwise, has expressed a similar opinion.[2]

That the importance of these questions has been recognized in Germany for some time was shown by the reports presented at the Fourteenth International Congress of Hygiene and Demography, held in Berlin, City Engineer Metzger (Bromberg) said there:[3]

"The many attempts to purify city sewage in the past, with the great activity that has been shown in relation thereto, would have led to better results if the resulting sludge were not a troublesome accompaniment, interfering with any satisfactory solution.......In most towns.....the removal of sludge was a *bête noir*, and many plants would have produced a more favor-

[1] *The Surveyor*, 1909, No. 886, p. 27.
[2] Sydney Barwise, Med. Officer of Health. *The Sanitary Record*, 1909, p. 122.
[3] Ges. Ing., 1908, No. 4, p. 50–53.

able impression if it had not been for the mountains of detritus. It was realized at last that all attempts to utilize sludge had led to unsatisfactory results.

"The removal and utilization of sludge is of such importance that no plant should be completed until all questions of handling sludge while avoiding the known nuisances are finally decided."

The principal trouble lies in the large amount of water, which is so difficult to remove. After it has been removed from the plant the sludge contains at least 70 per cent., usually 90 to 95 per cent., and occasionally 99 per cent. of moisture and is a liquid mass. Every manipulation of the material, whether with the view of utilization, storage or removal, is rendered more difficult and expensive by this ballast of water.

THE DRYING OF SLUDGE

CHAPTER I

Necessity of Drying

Utilization.—The value of sludge lies in the organic material contained in it. Heretofore this has been used as a fertilizer, by recovering the contained grease or by converting its calorific value into heat.

Fertilizing Value.—Its employment as a fertilizer has been most widespread. In small plants in an agricultural region the sludge can be disposed of and it is often possible to secure a small revenue therefrom, especially where the soil is dry and sandy. In large cities the farmers will seldom take the sludge when it is wet. They usually demand a spadable product.

The following example shows what difficulties were encountered in disposing of wet sludge even a few years ago.

The City of Edinburgh,[1] Scotland, in the year 1892, sent 1521 circulars to farmers in the neighborhood asking for proposals to take 58,100 tons (51,900 long tons)—*i.e.*, the accumulation of a half year.

Only 47 bids were received and all with the condition that the city pay for transportation, some even demanding a bonus for each ton removed.

Other large cities without suitable land for irrigation fields have had a similar experience. The farmers either refused to take the wet sludge or demanded compensation.

Dried sludge is more suitable for use as a fertilizer, but the cost is usually greater than the amount received. There are, to be sure, some exceptions. In Kingston-on-the-Thames[2] (near London), sludge obtained by the A. B. C. process (alum, blood, coal) and then dried by heat, was sold as "Native Guano" for about $15.10 per ton (70 M. per 1000 kg.), a price strangely in contrast to all other results.

[1] *Zentralblatt der Bauverwaltung*, 1892, No. 22, p. 240.
[2] Douglas, *Sanitary Record*, Vol. XL, No. 973, p. 424.

Charlottenburg[1], where an annual amount of about 23,636 cu. yds. (18,070 cbm.) of spadable sludge is obtained at the irrigation fields at Gatow, receives but 5.3 cts. per cubic yard (30 pfg. per cbm.). More than 9.1 cts. per cubic yard (50 pfg. per cbm.) is seldom paid and this, usually, only during the first years of operation. As soon as the farmers realize that the sludge must be disposed of they will offer nothing; and sometimes even demand compensation.

At Frankfort-on-the-Main the greatest difficulty was experienced merely to get rid of the spadable sludge. The large consumers demanded pay for cartage and the furnishing of labor for loading and unloading.

At Cassel[2] sludge composted with sweepings is given away.

At Leipzig,[3] also, where sludge is obtained by precipitation with iron salts and is comparatively cheap to dry, and where 12 cts. (50 pfg.) per load is received, or, from the lessees of the city, 6 cts. (25 pfg.) [where they do their own loading, 6 cts. (25 pfg.) less] there have been paid for the cartage of dried sludge from its places of deposit and received therefor:[4]

Year	Paid for cartage		Received for sludge and screenings	
	$	M.	$	M.
1905......	5,509.51	23,149.22	26.70	112.20
1906......	7,373.75	30,982.15	76.87	323.00
1907......	7,308.64	30,708.56	81.40	342.00

As the expense of cartage from the drying beds represents only a portion of the costs chargeable to sludge—there being, in addition, the establishment and maintenance of the drying beds, erecting a structure for loading, which appears in the budget for the year 1905, $2,483.68 (10,435.64 M.), besides interest and

[1] Geh. Med.-rat Prof. Dr. Salomon, Die städtische Abwässerbeseitigung in Deutschland. Vol. II, p. 186.

[2] Stadtbaurat Höpfner and Dr. Paulmann, Die Schmutzwasserreiningungsanlange der Stadt Kassel. *Vierteljahrsschrift für gerichtl. Medizin und öffentliches Sanitätswesen*, 1900.

[3] Inspected Dec. 7, 1908.

[4] Official report of the city of Leipzig.

sinking fund charges—this example shows how little we can count on a profit from the fertilizing value of sludge.

One of the principal difficulties in the use of sludge for farming purposes is the fact that fertilizers are usually used only during the winter months. As soon as it became possible to produce from the sludge a firm fertilizer the feasibility of its transportation was increased. The city of Frankfort-on-the-Main has made experiments in this direction, and manufactured poudrette in order to ascertain the cost of the process. Drying was necessary for this also. It was found, however, that even when it could be sold at market prices the excess in cost of manufacture amounted to $71,400 (300,000 M.) per annum.

The farmers object to using fresh sludge on their fields constantly because of the nuisances which arise therefrom. Sometimes it causes vermin to appear, it frequently brings the seeds of weeds and always much grease and cellulose. The latter makes the soil slimy, as has often been proven.[1] Efforts were then made to separate and destroy these materials, or at least to utilize them, especially the grease.

Utilization of Grease.—Sludge contains grease in varying amounts. It comes in sewage from wash water and other domestic refuse, from slaughter houses and from soap suds, and hence is found in the sludge. Based upon the dried material there was found in Lüttich[2] 18 per cent., in Cassel[3] 15 per cent., in Frankfort[4] 16.71 per cent. In Harburg[5] 14.2 per cent. in raw sludge and 8.5 per cent. in centrifuged sludge.[6]

No use has as yet been discovered for the grease obtained from sludge. The large amount of water contained renders it too costly. The experiment at Cassel is well known. At a cost of $47,600 (200,000 M.) a reduction plant was built where grease was recovered by the use of benzine after most of the water had been removed by filter presses, and the residue was used as a

[1] Dr. L. Haack, Berlin. Verwertung und Beseitigung des Klärschlammes aus den Reinigungsanlagen städtischer Abwässer. Gesundheitsingenieur. 1908, p. 53.

[2] Dr. Lacomble, Le sont des matieres grasses, etc. Revue de Phygiene et de police sanitaire. 28 No. 10.

[3] Stadtbaurat Höpfner and Dr. Paulmann, Mitteilungen aus der Kgl. Prüfungsanstadt für Wasservers orgung und Abwässerbeseitigung zu Berlin. Pub. by Aug. Hirschwald. Vol. I.

[4] Dr. Bechold and Dr. Voss; Zur Fettgewinnung aus Abwässern. Zeitschr. f. angew. Chemie, 1908, p. 1318.

[5] Regierungsbaumeister Reichle and Prof. Dr. Thiesing. Versuche mit dem Schlammschleuder apparat Schäfer-ter Meer. Mitteilung a. d. Kgl Prüf. Anst. f. Wasservers, usw. Vol. X, p. 190.

[6] Ditto, p. 154.

fertilizer. From 65 cu. yds. (50 cbm.) of wet sludge 6 1/2 cu. yds. (5 cbm.) of dry sludge was expected, from which 1650 lbs. (750 kg.) of crude grease and 10,750 lbs. (4885 kg.) fertilizing sludge was looked for. The latter was estimated at 32 1/2 cts. per 100 lbs. (3 M. per 100 kg.) to be worth $34.88 (146.55 M.). From the crude grease 990 lbs. (450 kg.) refined grease was realized, which was estimated, at $4.87 per 100 lbs. (45 M. per 100 kg.) to be worth $48.20 (202.50 M.), and 495 lbs. (225 kg.) of tarry residue which was estimated at 41.6 cts. per 100 lbs. (2 M. per 100 kg.).

The total revenue from 65 cu. yds. (50 cbm.) wet sludge was therefore estimated at $88.14 (353.55 M.). In spite of this the expenses were greater than the receipts, and the plant was abandoned and taken down. One reason for the failure, aside from the high cost of drying, was that the grease obtained was not marketable, on account of its disagreeable odor.

At Frankfort Bechold and Voss have made a very thorough study of the question of grease recovery, accompanied by many experiments. They avoid expensive drying and extract the grease from the wet sludge with benzine after treating with acid and heating to 140° to 158° F. (60° or 70° C.). Aside from the experimental plant, which is said to have given good results, the method has not as yet been introduced.

Experiments are also now being made by Dr. Grossmann at Oldham, near Manchester, to demonstrate the practicability of his method of recovering grease from sludge by distillation with steam. The method of Dr. Grosse-Bohle (Cologne)[1] by which sludge was heated to 122° F. (50° C.) to obtain the grease from the resulting scum has not yet been successful on a large scale.

If a substance contains 15 per cent. of grease, as is the case with the dried matter in fresh sludge, as shown by the analyses already given, the possibility of a profit is assured. As sludge contains from 90 to 95 per cent. of water, however, these figures, based on the wet material as delivered, will be materially decreased. 15 per cent. of grease in the dried material is only 1.5 per cent in the sludge 90 per cent. moisture, and 8.5 per cent. (centrifuge sludge from Harburg[2]) is only 2.34 per cent. in sludge with 72.5 per cent. moisture. The water is here again the great stumbling block to utilization. The prospect of utilizing the

[1] Hofrat Dr. Friedrich, Kulurtechnischer Wasserbau. 2nd Ed. Vol. II, p. 482.

[2] Inspected May 9, 1908. See also Dr. Ing. Bruno Heine, Das Kanalsationswerk der Stadt Cöpenick. Gesundheit, 1909, No. 19, 23.

grease contained would be greatly increased by some cheap method of drying.

Utilizing the Calorific Value of Sludge.—The drying of sludge is absolutely necessary to obtain its calorific value. Two methods of doing this have been attempted: by direct combustion and by conversion into gas. Sludge without some addition is seldom combustible, even when thoroughly dried. Experiments made and the plants constructed so far deal exclusively with mixtures with dust or else sludge precipitated with combustible material (coal or peat). At Cöpenick[1] and Potsdam[2] lignite sludge obtained by Degener's method (ground lignite and sulphate of alumina were thoroughly mixed with the sewage to be clarified) was used. In Cöpenick the preliminary drying is accomplished in sludge tanks, the next step takes place under a large shed after removal and it is finally dried out at the feed openings of incinerators. The heat generated is transformed into electricity by steam power. In Potsdam the sewage is clarified in towers (Rothe-Degener process) and the precipitated sludge is dried in filter-presses, made into briquettes and in part sold as fuel and in part used in the generation of electricity as at Cöpenick. In both cases coal is added to the sludge.

Efforts to obtain the calorific value from such lignite sludge have frequently been made, *e.g.*, by Heine[3] in the central office of the General Electric Co., at Berlin, and by Schury and Bujard[4] (peat clarified sludge) which have furnished good results.

Göhring,[5] as well as Reichle and Dost,[6] have published experiments on the conversion of sludge into gas. Other experiments of the kind have been made at Manchester.[7] No attempts to introduce this process on a large scale have been made.[8]

[1] Idem.

[2] Inspected May 8, 1908, and Nov. 28, 1908.

[3] Dipl.-Ing. Bruno Heine, Neber die Erzeugung electrischer Energie mit Hilfe von Kanalisationsklärschlamm. Dissertation. Tech. Hochschule, Berlin.

[4] Regierungsbaumeister Schury und Dr. Bujard, Torfbreiklärversuch der Stadt Stuttgart in der Kohlebrei kläranlage zu Tegel. Mitteilungen a. d. Kgl. Prüf.-Aust. f. Wasservers. usw. Vol. VIII, p. 143.

[5] C. F. Göhring. Beiträge zur Reinigung von städtischem und Fabrikabwasser. Leipzig, 1904.

[6] Regierungsbaumeister Reichle und Dr. Dost. Ueber Schlammverwertung durch Vergasung, insbesondere beim Rothe-Degenerschen Kohlbreiverfahren. Mitteilung a. d. Kgl. Prüf. f. Wasservers. u. Abwässerbes, Vol. VIII, p. 146.

[7] Baurat Bredtschneider und Dr. Thumm. Die Abwasserreinigung in England. Mitteilung a. d. Kgl. Prüf.-Anst. f. Wasserv. usw. Vol. III, p. 93.

[8] Aufsätze über Schlammverbrennung und Vergasung siehe R. Frank, Vergasung von Abwasserklärschlamm. Ges. Ing. 1907, p. 465, and Koschmieder, Tech. Gem. 1905, No 19.

Sludge is mixed with sweepings and burned in several places, as at Bury,[1] where the sludge dried by filter presses is mixed with street sweepings in the proportion of 1:2 and burned in Horsfall furnaces. This is also done at Hyde.[2] A large plant of this kind has recently been put up at Frankfort, but the process does not appear to be economical. An annual deficit in operating expenses of $17,612 (74,000 M.) was expected at the outset[3] as compared with the former minimum outlay for sludge disposal, $6545 (27,500 M.). The burning of sludge has also been planned at Pforzheim.[4]

The advantages of this method are undeniable. One is no more dependent on the good will of the former. The disposal of the sludge is assured and the nuisance overcome. No other method is so sanitary. Its general use is, however, prevented by the cost of drying. Here, more than with other methods, it is clear that the sludge question is essentially a question of drying.

Removal. Dumping at Sea.—As long as drying is so expensive, the burning of sludge may be classed with those methods of disposal in which no profit can be expected, and of these, it is the most costly. According to the Royal Commission on Sewage Disposal[5] the cost of drying and burning is estimated at 35.7 cts. (1.50 M.) for one long ton (1015 kg.) of wet sludge; while carrying it to sea costs but about 3.6 cts. (0.15 M.) when the distance is not too great. These methods are in use in London (Barking and Crossness[6]), at Manchester[7] and at Salford,[8] and are proposed for several other places, *e.g.*, Belfast. Cities not situated directly on the sea can use this method (those directly on the shore discharge their sewage untreated into the water, as at Copenhagen) provided there is some direct waterway to the sea and that the distance is not too great; otherwise the

[1] Dr. Ing. Schiele. Abwasserbeseitigung von Gewerben, etc. Mitteilungen. a. d. Kgl. Prüf.-Anst. f. Wasserv. usw. Vol. XI, p. 172.

[2] Idem, Vol XI, p. 781.

[3] Stadtrat Kölle und Stadtbauinspector Uhlfelder. Denkschrift über den Bau einer Müllverbrennungsanstalt zur Unschädlichmachung der Hausabfälle und des Klärbeckenschlammes in Frankfort a. M., p. 25.

[4] Stadtbaumeister Herzberger und Dipl.-Ing. Morave. Projekt einer Müllverbrennungsanstalt mit Klärschlammtrocknung für die Stadt Pforzheim. Ges.-Ing, 1907, No. 40, p. 649.

[5] Royal Commission on Sewage Disposal. 5th Rep. London, 1908. Wyman and Sons Ltd.

[6] Inspected May, 1907.

[7] Inspected Sept. 14, 1909.

[8] Inspected Sept. 14, 1909.

charges for transportation are excessive. At London the distance is about 62 miles (100 km.), at Manchester and Salford 50 miles (80 km.). London has a whole fleet of sludge steamers, each of which holds 1120 tons (1000 long tons) and costs $142,800 (600,000 M.), besides large iron tanks where the sludge is stored until the arrival of the steamer. Manchester and Salford have each one steamer. Three trips a week are made on an average. A 670 ton (600 long ton) steamer cost $57,120 (240,000 M.) in 1895 for Salford. Removal there costs about 17 cts. per ton [80 pfg. per long ton (1015 kg.)] of wet sludge; in Manchester, in 1902–3, 16.6 cts. per ton (78 pfg. per long ton).[1]

Influence of Drying on the Cost of Removal.—The following considerations show how the removal of water reduces the cost of every method of disposal where there is a question of transportation: if 95 per cent. is reduced to 90 per cent. there will be 9 parts of water to 1 part of dried matter, where before there were 19. There is, then, only 1/2 the original quantity to dispose of; with 80 per cent., 1/4; with 70 per cent., 1/6; with 60 per cent., 1/8; and with 50 per cent., 1/10. As fresh sludge with 70 per cent., and septic sludge with 60 per cent. moisture, has attained a consistency where it can be handled, like damp earth, and can be carried in any kind of wagon, drying to this point has a great advantage.

Placing on Land.—Drying is usually necessary when land instead of the sea is used as a dumping ground, partly on account of the smaller cost for transportation, which is much greater by land than by sea, partly to avoid the foul odors from the piled up sludge. Wet sludge, especially from sedimentation tanks, emits a very foul smell after a short time, which can be recognized for a long distance. By drying until it can be spaded this difficulty is overcome.

This is done at Hanover[2] after de-watering by a centrifugal machine.

The drying of sludge is necessary to reduce the cost of transportation and to obtain its calorific value. It frequently renders it available as a fertilizer. All nuisances and costs occasioned by sludge would be reduced to a minimum if a dry product could be obtained. In the main, therefore, the sludge question

[1] G. Ashton (Manchester). Disposal and Utilization of Sewage Sludge. *Surveyor*, 1904, p. 320.

[2] Inspected Nov. 18, 1907, May 6, 1908, and Nov. 21, 1908.

is a question of drying. Sludge, however, has a great aversion to drying.

Methods of Drying Different Kinds of Sludge

Classification of Methods.—Different methods of clarification produce different kinds of sludge. These show very different characteristics, especially in the matter of drying.

Mechanical methods of clarifying can be divided into "fresh methods" and "septic methods," as regards the final condition of water and sludge. In the first, putrefaction is prevented in order to keep the sewage fresh; in the second it is promoted to digest the sludge. Between the two is the Emscher method, or similar ones, where the sewage is kept fresh, but the sludge is subjected to thorough decomposition.

CHAPTER II

Drying of Fresh Sludge

Source.—Arrangements used in the fresh methods (sedimentation and precipitation) are in general a widening of the cross-section of the channel, by which the current is retarded. Material which is capable of settling is thus given the opportunity. These arrangements are in the form of tanks (horizontal movement of the water), or wells or towers (vertical movement). The water, as a rule, takes from 1 to 4 hours to pass through. Sludge which settles on account of its weight (plain sedimentation) or whose separation is increased or facilitated by the addition of chemicals to the sewage, causing the flacculent matter to settle (precipitation method) is removed before it putrefies. Tanks for this purpose are usually entirely emptied. Wells and towers are frequently so arranged that the sludge can be removed under water by pumps or vacuum receivers without interruption of operation.

Characteristics of Fresh Sludge.—Fresh sludge is marked by the great amount of water contained. This is 90 to 95 per cent. on an average, according to data given by Bredtschneider and Thumm,[1] Imhoff,[2] Dunbar,[3] and von Schiele.[4] Reports on the examination of sludge from different plants confirm these figures. Thus in Cologne Grosse-Bohle[5] found between 91.34 per cent. and 95.57 per cent., and Tillmans[6] found at Frankfort-on-the-Main an average of 91.07 per cent. I have never found less than 90 per cent., but often more—up to 96 per cent. Hönig[7] found in Brünn the surprising amount of 99 per cent.

[1] Die Abwasserreinigung in England. Mitteilungen a. d. Kgl. Prüf.-Anst. f. Wasserv. usw, Vol. III.

[2] Regierungsbaumeister Dr. Ing. Imhoff. Die biologische Abwasserreinigung in Deutschland. Mitteil. a. d. Prüf. Anst. f. Wasserv. usw, Vol. VII.

[3] Leitfaden für die Abwasserreinigungsfrage.

[4] Abwasserbeseitigung von Gewerben, etc. Mitteilungen a. d. Kgl. Prüf.-Anst. f. Wasserv. usw, Vol. XIII.

[5] Die Probeklärunglage zu Koln-Niehl. Mitteilungen a. d. Kgl. Prüf.-Anst. f. Wasserv. usw, Vol. IV.

[6] Die Kläranlage in Frankfurt a. M. Wasser und Abwasser, Vol. I, p. 320.

[7] Gewinnung und Verwertung von Städtischem Klärschlamm. Ges. Ing., 1910. Nos. 1 and 2.

On account of this large amount of water, fresh sludge from city sewage is a very liquid material. It can be concentrated after standing several days, when roily water appears at the surface, but it is seldom possible to reduce the moisture much below 90 per cent. More than half of the 5 per cent. to 10 per cent. dried substance consists of organic matter. This decomposes very readily, giving a characteristic indefinable penetrating odor. The nuisances arising from this odor prevent the storing and further treatment at the plant, when the neighborhood has become built up. Disposal plants have therefore been placed at a great distance from the source of the sewage, and where for any reason this has not been done, the inhabitants have raised much objection. In Braunschweig,[1] *e.g.*, the operation of a plant where fresh sludge was produced, and where it was to be dried, had to be abandoned. Since then the sewage has been spread on irrigation fields.

At Frankfort-on-the-Main[2] the odors were overcome by spraying with tarry, floating oils (facilol and Belloform) and also covering the surface with peat.

At other places, *e.g.*, in Remscheid,[3] Langensalza and Aschersleben[4] (wells of the Mairich system) attempts have been made to reduce the odor by placing the sludge beds on hills and pumping the sludge up at a great cost. The odor was thus dispelled by the wind.

Quantities of Fresh Sludge.—The unpleasant features connected with sludge are so much felt because of the large quantities which accumulate. According to Imhoff,[5] 0.32 gallons (1.2 liters) of sludge with 95 per cent. moisture per inhabitant per day accumulate in plants of large cities where the sedimentation process is used. For a city of 100,000 inhabitants this gives an annual amount of 56,000 cu. yds. (43,000 cbm.) of sludge which must be cared for.

Drying.—As shown above, since drying reduces the volume, it is almost always a necessary preliminary in caring for sludge. Fresh sludge is obstinately opposed to drying. The main difficulty lies in overcoming the attraction of the colloidal substances for water. These are present in the form of hydrosols as well as

[1] Salomon. Die stadtische Abwasserbeseitigung in Deutschland. Vol. II, p. 21.
[2] Inspected Dec. 7, 1908.
[3] Inspected Aug. 27, 1908.
[4] Inspected Dec. 4, 1908.
[5] l. c., p. 40.

hydrogels. According to van Bemmelen[1] the gels are membranes formed by precipitation which form a network of amorphous connected parts which are swelled up by the liquid absorbed. The structure of such "micells" is described by von Bütschli[2] as honeycombed. The hypothesis of a greatly enlarged surface would best explain the peculiarly stubborn retention of water in fresh sludge.

Drying in the air in Sedimentation Tanks.—Difficulties attending the drying of sludge and the great expectations entertained have rendered the development of different methods most timely.

The most primitive method—that of letting it lie in the tanks out of use in intermittent operation has been tried at the Königsberg[3] irrigation fields, where the foul odors from decomposition could do no harm. Two settling tanks used for preliminary clarification for irrigation, which were filled alternately with sludge, were used there as drying basins, as the farmers refused to take the wet sludge, even when it was given them. This method was soon seen to be unsuccessful. As was to be expected, the sludge did not become spadable when wanted, so that considerable cost was entailed for removing the wet material.

The same method of drying, however, has been in use for years at Cöpenick,[4] near Berlin. Sludge procured by precipitation with large amounts of lignite and an addition of aluminum sulphate is not to be compared with ordinary settled sludge in its physical attributes.

In Special Tanks.—At other places, formerly at Braunschweig, Cassel, Frankfort and still in Wimbledon and Huddersfield,[5] England, Essen, Remscheid and Elberfeld-Barmen, and recently in different English plants, Birmingham, *e.g.*, special tanks are used, partly with paved or masonry sides, partly with simple earth embankments. This plan was abandoned at Cassel, because the sludge would not become firm, in Braunschweig[6] because of the bad odors. Dunbar writes about Wimbledon:[7]

[1] Dr. Victor Pöschl. Einführung in die Kolloidschemie, Dresden. 1908. Von Bemmellen. Die Absorption; Bildung und Struktur des Gels. Zeitschrift f. anorg. Chemie, Vol. XVIII.

[2] Bütschli. Untersuchungen über Mikroskopische Schäume und das Protoplasma. Leipsig, 1892. See also, *Zeitschr. f. anorg.* Chemie, Vol. XXIII, p. 326.

[3] Salomon. Die Abwässerbeseitigung in Deutschland, Vol. II, p. 696.

[4] Inspected May 9, 1908.

[5] Inspected May 13, 1909.

[6] Stadtische Festschrift für die Teilnehmer an der Versammlung Deutscher Naturforscher und Aertze. Braunschweig, 1898. Ref. Salomon, Vol. II, p. 21.

[7] Prof. Dr. Dunbar. Leitfaden f. d. Abwasserreinigungsfrage, p. 376.

"It is difficult to separate the water from the sludge. All efforts to drain it have failed. If it is allowed to stand in open tanks with a porous bottom it is often months before it can be removed with spades. Each rain reduces it to its original condition. In Wimbledon after six months' treatment it formed a thick liquid mass of highly offensive character and 77.5 per cent. water. If this mass of sludge is deposited in lagoons, as is often done in England, the whole neighborhood suffers from the unbearable nuisance."

In Essen sludge obtained by clarifying with lime in Rothe-Röckner towers is placed in gigantic earthen basins where it slowly digests. The water rising to the surface can be drawn off by some device. Odors are here exceptionally slight, as the hydrogen sulphide is combined with iron. This plant also is soon to be abandoned.

The method was nearly the same at Frankfort. When it was seen how great the cost and how bad the conditions were, mechanical means of drying were resorted to.

This method of drying was tried at Elberfeld-Barmen[1] in spite of the failures experienced elsewhere, and huge tanks were built, which had to be increased in number at the end of a year, into which the fresh sludge was pumped. As was to be expected, the sludge required a long time to become spadable, and it became putrid.

Another example is seen in the wells of Mairich. There are two such plants at Remscheid. In one the attempt is made to dry the sludge in tanks 3.3 ft. (1 m.) deep, where it is to drain through walls made of broken stone. Up to September, 1908, after it had been in operation two years, the sludge had not become spadable in any of the tanks. In the other plant the draining was to take place through fascines. There it was found that the decomposed sludge would not drain through the fine fascines, and simply ran through where they were loosely woven.

Spreading in Thin Layers.—Fresh sludge dries more quickly and without much decomposition where it is spread out in thin layers.

A method founded on this idea has been successfully used where the necessary areas are available, and where the odor causes no nuisance. The sludge is spread on sandy soil if possible. It dries there, according to its condition and to the weather in a few

[1] Inspected April, 1908.

days or weeks, and can then be dug under or carried off. This can best be done where, as at Charlottenburg, the sludge obtained from preliminary clarification is spread on irrigation fields.

In Germany it is used at Mannheim and on several irrigation fields That it is not cheap even there is shown by the fact that in the year 1906 clarification of the daily amount of sewage, 9,246,000 gallons (35,000 cbm.), cost $2530 (10,633 M.), while the removal of 92 to 105 cu. yds. (70 to 80 cbm.) sludge cost $5,572 (23,410 M.)—more than twice as much—although the areas used for drying were in the immediate neighborhood of the plant.

Similar experiments have been tried in recent years at Birmingham, where the sludge was spread on fields to dry. It was shown that the sludge dried after a while, but such large areas were necessary that it became impracticable.

Burying.—The so-called burying method, by which the sludge is dried and disposed of at the same time, is much used in England. The sludge is not spread upon the disposal areas, but pumped into dry furrows, where a large percentage of the moisture is absorbed into the loose soil; as soon as the sludge is firm enough to support the earth the furrows are filled in. If sludge that has decomposed under water is used, the same area can be used successively every three years, according to Travis,[1] as is done at Hampton[2] and Birmingham.[3] Where fresh sludge is used, and especially where chemical precipitation has been employed, this is not possible, as has been demonstrated at Birmingham and in experiments made by the Emscher Association, as the earth in which it is buried will not drain it. In Birmingham Dr. Dunbar[4] saw samples of lime sludge which had been buried more than 20 years and which retained the original fecal odor, and was as hard as blue clay. Sludge which had begun to putrify was buried, as an experiment, at Recklinghausen, and at the end of a year it had its original odor, and was sticky and slimy, while digested sludge could not be distinguished from humus.

Fresh settled sludge, even when not precipitated with lime, dries very slowly in such ditches. I convinced myself of this at Birmingham. Unlimited areas were there covered with such

[1] W. Oven—Travis. Some observations relating to bacterial tanks operations. Trans. Soc. Civil and Mechanical Engrs. London, 1906.
[2] Inspected May, 1907.
[3] Inspected Sept. 15, 1909.
[4] Prof. Dr. Dunbar. Die Abwasserreinigung von Birmingham. Ges.-Ing. 1908.

sludge-filled ditches, and as no satisfactory results were achieved it was decided to return for the present to the method, already mentioned, of storing in lagoons.

In Insterburg[1] sludge 8 days old is disposed of by this method of burying, but nothing has been published as to the results obtained. It is doubtful whether the same ground can be used again for several years when sludge that is only partially decomposed has been applied. If one is not obliged to use the same area at short intervals, as in the case of small plants in agricultural regions, this method is free from objection and is to be recommended.

Composting.—Similar to the method of plowing under and burying, which involves a rough mixing of the wet sludge with a drier, porous substance—the earth—is a method much employed in small plants—*i.e.*, mixing with street sweepings, or composting. This is done, *e.g.*, at Göttingen and Cassel in Germany. Where these heaps of compost are not quickly used by farmers they are, of course, liable to become a nuisance.

Filter-beds.—As fresh sludge may be considered as solid material floating in a liquid, the next step was to separate these component parts by filtration. This, too, has been tried at different places and with various modifications, but without success, at least to the extent that the sludge, although separated out, later clogged the filter and decomposed.

In Allenstein,[2] *e.g.*, the attempt was made to drain the water (90 per cent.) from the sludge on carefully prepared gravel filters. The filters soon became clogged, however, and the sludge decomposing on it produced such a nuisance by foul odors that the plan had to be abandoned.

In Bielefeld the detritus from the preliminary cleansing in preparation for irrigation is drained in a similar manner. In the report for the year 1905 the municipal authorities state:

"The removal of the sludge settling out in the clarification tanks, in which large volumes deposit, causes difficulties which should not be underestimated. In designing new plants it is strongly urged that drying beds of ample size be provided. The original number is at present being increased by two more. It is hoped thus to effect a speedier removal of the sludge. The water drawn off from the drying beds is again clarified and used for

[1] Salomon. Die städtische Abwässerbeseitigung in Deutschland. Vol. II, p. 687.
[2] Salomon. Vol. II, p. 17.

irrigation, so that the effluent may be carried to the outfall in a clean condition."

In Leipzig[1] a part of the sludge, which is precipitated with salts of iron, is led into earthen lagoons. These have drain pipes laid on their level bottoms, over which is laid a 12-in. (30 cm.) layer of gravel, and on this are laid tiles with close or open joints, filled with sand. The water from the sludge filters through to the drain pipes and is brought to the plant for a second clarification. In summer the sludge often becomes spadable in 2 months; in winter in 4 or 5 months. As the tanks are inadequate the greater part of the sludge has to be disposed of by being conveyed to an old river bed.

These examples show that the mere filtration of fresh sludge is only feasible where there are large areas and ample time for the process, and that a nuisance from putrefaction may be expected. Means have therefore been sought to reduce the time and area required for filtration. Filter-presses and centrifugal machines used in certain chemical industries were recognized as such means.

Filter Presses.—Filter presses have been employed for a long time at several places as an experiment, *e.g.*, at Cassel and Frankfort. The general conclusion is that they are expensive to maintain and operate and that they possess little efficiency. At present they are only used in Germany with the lignite process, *e.g.*, in Potsdam, Spandau and Tegel. In Potsdam it is sometimes impossible to press the lignite sludge dry, although it is comparatively easy to separate it from the water. According to reports furnished me, 8 to 10 per cent. of the pressed sludge is too moist. This, even when pressed into briquettes for fuel, becomes soft again in the rain, so that it is necessary to store it under shelter. Filter presses are no longer used in Germany in large plants for the purpose of de-watering fresh settled sludge.

In England, on the contrary, filter presses are much used, especially where lime is employed as a precipitant. Sludge with lime is more easily pressed. Sludge from plain sedimentation usually requires a large addition of lime entailing a great expense.

Drum Filters.—The dry process, described by Hönig,[2] which

[1] Verwaltungsbericht der Stadt Leipzig und Mitteilungen aus dem Tiefbauamt. Plant inspected Dec. 7, 1908, and May 10, 1910.

[2] Prof. M. Hönig. Ueber Gewinnung und Verwertung von städltschem Klärschlamm. Ges.-Ing., 1910. p. 26.

has been tried at Brunn, is based upon filtration. The p
is produced by a vacuum under the filtering surface.

Centrifuges.—More recently great hopes have been pla
centrifugal machines.

The city of Frankfort-on-the-Main[1] has conducted ve
haustive experiments with this method. It may now be
operation on a large scale at Harburg,[2] Hanover[3] and Fra

Modern centrifuges differ favorably from the old filter
in that all manual labor is avoided, so that the workme
no longer come in contact with fresh sludge containin
matter or garbage. As yet little has been published re
the cost and efficiency of this process. Reichle and Th
who have examined and described the centrifugal plant
burg, give as the cost of de-watering with centrifuges 6
per cubic yard (3.42 M. per cbm.) of dried sludge, wit
presses 42 cts. per cubic yard (2.31 M. per cbm.) under
conditions. As the cost was the principal objection to th
duction of filter presses the outlook for centrifugal mac
not very good. It is still worse because filter presses pr
drier sludge than centrifugal machines, and because th
produce a highly offensive liquid on account of the large
of organic matter contained (according to the above aut
3.7 per cent. dried matter of which 91 per cent. is o
It is not to be compared with the liquid from filter pres
can be seen at Harburg, Hanover and Frankfort. The
usually a transparent, pale yellow liquid, as is seen at
England,[5] while the effluent from centrifugal machines is
watery sludge.

In spite of these drawbacks centrifugal machines r
employed where the agricultural utilization of sludge
practicable especially where there is no cheap land a
for storing the wet sludge. Frankfort-on-the-Main has
chosen this method.

Drying by Heat.—Three years ago an attempt was
Potsdam to dry sludge by heat. The lignite sludge
there, which was first dried in filter presses, and whic

[1] Zentrifugen. Schäfer-ter Meer System
[2] Inspected May 7, 1908.
[3] Inspected Nov. 18, 1908.
[4] Bauinspektor Reichle und Prof. Dr. Thiesing. Mitteilungen a. d. Kgl. P
Wassersorgung, etc. Vol. X.
[5] Inspected Sept. 13, 1909.

intended to used as fuel on account of the latent energy in the lignite, was manipulated experimentally in rotary ovens with fuel gas. Similar attempts are now being made at Frankfort for the further drying of centrifuged sludge containing about 70 per cent. moisture.

Electro-osmose.—Experiments have also been made at Frankfort with the electro-osmose process of Count Schwerin, to dewater more easily slimy sludge which, as already mentioned, is difficult to dry.

Dr. Tillmans[1] writes of this method that it prevents the colloidal condition of the sludge liquor for a while, but that this appears later. The current used is great but not prohibitive.

More extensive experiments were to have been made at Frankfort, but the results have not yet been published.

Results of the Methods of Drying Already in Use.—As regards the results obtained the methods of drying of fresh sludge can be divided into two groups: those in which there is a steady drying but which are expensive to install and operate (filter presses and centrifugal machines) and those which cost less but give no assurance of effecting the desired result (draining, irrigation and burying).

The problem of rational drying has not yet been solved. The septic process gives a better prospect of success.

[1] Dr. J. Tillmans, Zeitschr. f. d. Unters. d. Nahrungs. u. Genussmittel. Vol. XIV (1907), Parts 1 and 2

CHAPTER III

Drying Septic Tank Sludge

Source.—The apparatus for septic treatment differs from that for plain sedimentation by its greater size.

Septic Tank Method.—The time of flow through septic tanks is usually from 12 to 24 hours, during which it decomposes to a greater or less extent, according to its composition. The sludge is stored under water as long as possible. The capacity is generally arranged so that it can remain from 6 to 12 months. The easily disintegrated portions are removed by digestion. The gases which develop bring up particles of sludge which form a floating cover. The removal of sludge is performed in the same manner as with tanks for plain sedimentation.

Disadvantages of the Effluent.—The original aim in the septic treatment was to clarify the sewage more thoroughly than was possible by plain sedimentation. To-day it is known[1] that the storage of the large quantities of sewage from a city until it is entirely decomposed is practically impossible. It is still believed by many that permitting the sewage to become partially septic will produce as good a biological clarification as when treated in a fresh condition. That is not the case; the anaerobic bacteria are favored and the process of reduction initiated by the customary 12 to 24 hours' storage in septic tanks. The reduction is indicated by the formation of NH_3, H_2S and CH_4, and the decrease of N_2O_5 and N_2O_3. With the biological purification which follows, whether by irrigation, intermittent sand filtration, contact beds or the self-purification that takes place in a stream, active aerobic organisms are required, and it proceeds as a process of oxidation. The activity of the anaerobes must first be checked and the products of decomposition in the water must again be oxidized. Purification is therefore retarded by the septic process. Lübbert says of this:[2] "A medium is introduced into contact beds with the septic sewage which offers conditions

[1] Prof. Dr. Dunbar. Leitfaden für die Abwasserreinigungsfrage, pp. 127 and 140.
Dr. Lübbert. Einführung in die Frage der Abwasserreinigung. Zeitschr. d. Vereins Deutscher-Ing., 1909, Nos. 1–4.
Dr. Lübbert. Die Abwasserreningung im Kleinbetrieb. Ges.-Ing., 1909, p. 265

[2] Dr. Lübbert, l. c.

diametrically opposed to those desired, and the work of the oxidizing micro-organisms is rendered more difficult if they are to conquer in a struggle in which their antagonists, the ferments and decomposing agencies, have the upper hand."

Another unpleasant result of the septic method is often the unsatisfactory sedimentation which takes place in the tanks. The gases rising from the sludge at the bottom interfere with the settling action and bring up flakes of sludge. Particles fall from the scum. In spite of all precautions, such as scum boards and the arrangement of the outlet openings far below the water surface, the effluent is not as clear as in plain sedimentation plants; it is thus sometimes necessary, as at Birmingham, to insert sedimentation tanks and roughing filters between septic tanks and contact beds.

Further, the septic effluent usually contains much sulphureted hydrogen which is dispersed in the air by the subsequent distribution of the sewage on contact beds, especially if this is done with a sprinkler nozzle or revolving sprinklers, producing much worse odors than the worst sludge.

Sewage is, therefore, detrimentally affected by the septic treatment. In handling the sludge, however, decomposition offers distinct advantages.

Advantages for the Sludge.—Sludge which lies submerged for months at a temperature not too low, undergoes a profound alteration. Its organic constituents are attacked by putrefaction and the products of decomposition partly disappear in the form of gas. There has been much discussion concerning the amount of sludge consumption and a large amount of literature exists on the subject, but the question of amount does not touch the kernel of the matter. The quantity of organic material destroyed is much less important than whether the sludge acquires desired qualities by septic treatment.

Characteristics of Septic Sludge.—Sludge treated in efficient septic tanks differs from fresh sludge by its color, which is usually very black on account of the iron sulphide contained, by its less disagreeable odor, by its greater concentration—it contains 20 per cent. of dried matter as compared with 5 to 10 per cent. in fresh sludge—and by the ease with which it drains. These last differences are most important in treatment. They arise from the destruction of the water-binding colloidal substances. They are of the utmost importance in drying.

Drying Septic Sludge.—Drying by burying, which is very difficult with fresh sludge, is easily accomplished with septic sludge. This method has been used in Hampton for the past 5 years. In Birmingham there were no difficulties with burying so long as septic sludge was produced. Drying on porous areas is more easily carried on than with fresh sludge, because it drains so readily. In Unna[1] it became nearly spadable in the comparatively short time of from 4 to 6 weeks. In Mülheim-Ruhr,[2] where it is piled 3.3 ft. (1 m.) high, it takes from 8 to 12 weeks in summer to become spadable. Fresh sludge requires as least one year. Septic sludge, on the other hand, is not so well adapted to treatment in filter presses[3] or centrifugal machines.[4] This is of little consequence, however, as these costly devices are only resorted to when cheaper methods, such as draining the fresh sludge, fail.

Decline of the Septic Method.—Although the advantages of septic treatment have been known for years and been uniformly confirmed, it is steadily declining on account of its disadvantages and the cost of the plant

The construction and maintenance of a septic treatment plant are expensive, because the capacity required for the storage of the sewage must be taken at from 6 to 12 times that for plain sedimentation—which is usually 2 to 4 hours.

Large plants are constantly being converted from the septic tank process to plain sedimentation. In Manchester, *e. g.*, whole rows of septic tanks—one-third of the entire installation—have been changed to sedimentation tanks, and in Birmingham, also, which has the largest plant in the world, the greater number of the former septic tanks have been changed to tanks for plain sedimentation, in spite of the objectionable characteristics of fresh sludge.

Former advocates of the septic principle are now constructing sedimentation plants, *e.g.*, Travis at Norwich[5] in which not only is the sewage to remain fresh, but by which the sludge is to be removed at short intervals, as in the process of plain sedimentation.

[1] Inspected May 15, 1908.

[2] Inspected May 15, 1909.

[3] Royal Com. on Sew. Disp. 5th Rep. London, 1908.

[4] Nach Angaben der Hannoverschen Maschinenbau-A.-G. vorm. Georg Egestorff (Zentrifugen System Schafer-ter Meer) und Mitteilungen aus d. Kgl. Pruf Anst. f. Wasserv. u. Abwässerbeseit. Vol. X, p. 192.

[5] Inspected Sept. 17, 1909. Lit: *Surveyor*, 1908. Nos. 855 and 856, p. 672.

CHAPTER IV

THE DRYING OF EMSCHER TANK SLUDGE

Emscher Tanks.—Midway between the sedimentation and septic processes of sewage purification and sludge treatment is the method exemplified by the Emscher tank The details of construction are made clear by various illustrations.[1] In the Emscher tank clarification takes place in a chamber from which the sludge is drawn off continuously and automatically. The liquid passes through the chamber in from one to two hours. Because of this brief period of clarification and the immediate removal of the sludge, putrefaction of the liquid occurs less than is often the case in treatment by sedimentation.

Action in the Sludge Chamber.—The sludge flows from the sedimentation chamber into a well-shaped compartment below, in which it remains, on an average, two or three months.

The processes which go on in this sludge chamber, so far as they have been ascertained, are essentially different from the putrefaction in ordinary septic tanks with currents passing through them; for the gases, escaping in large quantities, unlike those in septic tanks, contain very little hydrogen sulphide. They consist mostly of methane and carbonic acid. The apparent cause of this phenomenon is the fact that the liquid covering and surrounding the sludge is renewed to but a very slight extent. It becomes, accordingly, thoroughly septic very quickly. The albuminous matters that have been set free in it are decomposed and can form no more hydrogen sulphide. In septic treatment, on the other hand, fresh sewage is continually brought into contact with the putrefying sludge and decomposes, so that the suspended as well as the dissolved albuminous matters are continually being acted upon, developing hydrogen sulphide.

From the sludge itself either very little hydrogen sulphide is developed, or else it decomposes, or the sulphur is otherwise combined. Investigations of this question are now being taken up.

Removal of Sludge.—The sludge is drawn off through iron

[1] 1. Dr. Ing. Imhoff, D. R. P. No 187,723, Kl. 85. c.

2. Regierungsbaumeister Helbing. Die Durchführung des Emschergenossenschaft gesetzes. Tech. Gem., Vol. X, No. 13.

3. Baurat Middeldorf. Die Arbeiten der Emschergenossenschaft. *Deutsche Bauzeitung*, 1909. Nos. 78, 79, 81.

4. Dr. Ing. Imhoff, A New Method of Treating Sewage. *Surveyor*, 1909. No. 905.

pipes which reach to the bottom of the tanks and lea through the side of the tank about 3 1/3 ft. (1 m.) below tl face. When the valve closing the end of the pipe projectir the tank is opened, the sludge is forced out by the weight liquid. This does not interrupt the process of clarificatio

Character of the Sludge.—Experience has so far indicate sludge from Emscher tanks exhibits in a higher degree favorable properties of that from septic tanks.

Amount of Moisture.—The water contained is decidedly in amount than that in sludge from septic tanks, althou Emscher sludge is always drawn off under water. In 10 a of the digested sludge from the Recklinghausen-Ost clarif plant (Table I) I found an average of 79.34 per cent. mc in 16 analyses from the Essen-Nordwest plant (Table average of 75.6 per cent., and in 6 analyses from the B plant (Table III) an average of 75.88 per cent. Each o samples was an average sample from a larger amount of (52.3 – 123.0 cu. yds. = 40 – 94 cu. m.). The greatest a of moisture found at Essen-Nordwest was 81.8 per cent. (C 1909, when there was only a thin layer of sludge in the The least was 71.35 per cent. (May 8, 1909). Of the 16 a samples taken, 9 contained less than 75 per cent. moistur

TABLE I (Condensed)

Recklinghausen Clarification Plant. (6 Emscher Tan

Summary of Analyses of Wet Decomposed Sludge from sampl from June 14, 1907, to July 26, 1909.

	Per cent.	
	Ave.	Max.
Wet sludge		
Moisture contained	79.34	84.2
Dried material	20.66	25.0
Dried material		
Mineral matter	54.8	64.4
Organic matter	45.2	55.9
Nitrogen	1.56	1.71
Fats[1]	6.41	6.75

[1] Analyses made on two days only.

TABLE II (Condensed)

ESSEN-N. W. CLARIFICATION PLANT (9 EMSCHER TANKS)

Summary of analyses of Wet Decomposed Sludge from samples taken from Apr. 8, 1909, to Oct. 11, 1909.

	Per cent.		
	Ave.	Max.	Min.
Wet sludge			
Moisture contained	75.6	81.8	71.35
Dried material	24.4	28.65	18.2
Dried material			
Mineral matter	45.08	53.51	37.6
Organic matter	54.92	62.4	46.49
Nitrogen	1.22	1.43	1.015
Fats[1]	4.89	7.36	3.44

[1] Analyses made on seven days only.

TABLE III (Condensed)

BOCHUM CLARIFICATION PLANT (18 EMSCHER TANKS)

Summary of analyses of Wet and Decomposed Sludge from samples taken from Feb. 11, 1909, to Aug. 13, 1909.

	Per cent.		
	Ave.	Max.	Min.
Wet sludge			
Moisture contained	75.88	79.71	72.97
Dried material	24.12	27.03	20.29
Dried material			
Mineral matter	59.49	63.98	49.3
Organic matter	40.51	50.7	36.02
Nitrogen	1.102	1.46	0.87
Fats[1]	8.73	12.3	5.82

[1] Analyses made on four days only.

10

ANALYSES OF WET AND DECOMPOSED SLUDGE

	Clarification Plant at	
	Workman's Mine "Schwerin" near Rauxel i. W.	Beckum i. W.
Number of tanks	2	
Date	Nov. 6, 1909	Dec. 1, 1909
Wet sludge	Per cent.	Per cent.
Moisture contained	80.4	77.6
Dried material	19.6	22.4
Dried material		
Mineral matter	49.0	64.0
Organic matter	51.0	36.0
Nitrogen	....	1.34
Fats	....	2.61

With 70 per cent. moisture Emscher sludge is still like gruel in consistency. It is completely mobile, flowing of itself in slightly inclined channels. It can also be raised from the bottom of the tank by means of an ordinary trench (membrane or diaphragm) pump. Fresh sludge of the same degree of concentration (70 per cent. moisture) is generally rather firm.

This peculiar difference is in part due to the fact that the fibrous or clogging constituents are almost entirely destroyed, and in part to the microscopic gas bubbles which take the place of the water between the separate particles of solid matter which, being surrounded by minute fluid films, renders the entire mass mobile.

Odor.—The odor of wet Emscher sludge can only be detected near by, and is only noticeable when it has been warmed to 158 or 176° F. (70° or 80° C.). It smells like rubber, or sometimes like tar or peptone. No disagreeable odors can be perceived a few feet away, even when the sludge is being drawn off

Analytical data of the organic material, fats and nitrogen contained can be found in Tables I to III.

Drying.—Only methods based upon drainage need be considered with reference to the drying of sludge from Emscher tanks, according to the following experiments, as they show that these methods are the simplest and cheapest besides being particularly adapted to Emscher tank sludge.

Experiments with Draining

General Remarks.—The question of the facility with which sludge which has decomposed under water may be drained and

the reasons underlying this have not yet been thoroughly investigated. At the experimental plant of the Emscher Association at Essen-Ruhr in 1907, it was shown that the sludge received there, when placed on porous material to a depth of about 10 in. (25 cm.) frequently became spadable in 8 to 10 days.

The tank from which the sludge came was built in 1906 by Baurat Middeldorf and Engineer Wattenberg after an English model—that of Travis at Hampton[1] (Middlesex). At the suggestion of Dr. Imhoff it was altered before being put into service so that the chamber which received the sludge and where it was to decompose would, in distinction from the Travis tank, have no current of sewage passing through it. This was, therefore, the first application of the Emscher tank treatment. It differed in outward form from the true Emscher tank in being more shallow. This has an unfavorable influence on the contained moisture and the time required for drying.

The amount of water contained is an important factor in the drying of sludge. The less water it contains the more quickly it dries. Fresh sludge often contains over 90 per cent. of water, sometimes 95 to 97 per cent. That obtained from the shallow tanks of the experimental plant had an average of less than 90 per cent. It is therefore possible that the rapid drying was a result of the small amount of moisture contained and was due to evaporation rather than to drainage. As no large amount of drainage water was observed, it was inferred that draining played no important part in the process of drying. After altering the drying beds I succeeded in securing and measuring large amounts of drainage water.

Experiment I

The Drying Bed.—The drying bed for the experimental plant is 65.6 ft. (20 m.) long and 16.4 ft. (5 m.) wide. The bottom is of fairly impervious clay and the walls of masonry in cement mortar. It is filled to about 20 in. (1/2 m.) in depth with coarse boiler clinker, over which a layer of fine clinker 6 in. (15 cm.) thick is spread. Drain pipes connecting at right angles with a collecting drain serve to draw off the wnter. It is divided by planks into 5 compartments of 215 sq. ft. (20 qm.) each.

Before the experiment was begun I altered the filling material

[1] Dr. Travis, Hampton. *Surveyor*, 1905. No. 703.

and provided the basin with diagonal drainage in place of the original drain.

Carrying Out the Experiment.—July 8, 1907, 31.4 cu. yds. (24 cbm.) of digested sludge from the experimental tank was placed on the drying bed thus prepared. The specific gravity of the wet sludge was 1.033. 27.8 tons (24.8 long tons) were consequently delivered. The depth was about 9 1/2 in. (24 cm.). Analysis of an average sample of the wet sludge showed 92.34 per cent. moisture. Of the 27.8 tons (24.8 long tons), therefore, 25.6 tons (22.9 long tons) were water. The sludge became spadable in 8 days. During this time 1833 gallons (6.94 cbm.) of drainage water was obtained=30.16 per cent. of the original amount of water. The firm sludge examined a few days later contained 65.4 per cent. moisture. The amount was then found to be 4.14 tons (3.7 long tons). It still contained 2.69 tons (2.4 long tons)

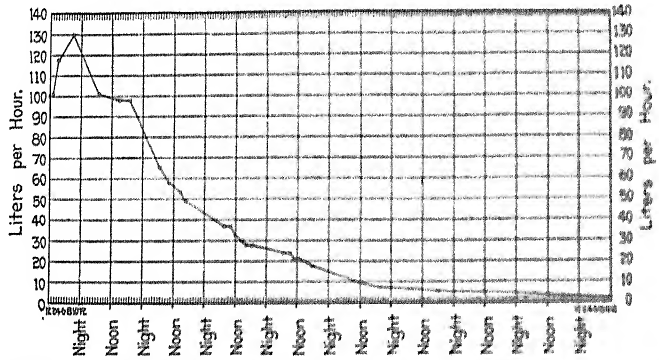

FIG. 31.—Drainage of sludge at the experimental plant July 8 to July 17, 1907.

of water. The loss of water was, therefore, 22.96 tons (20.5 long tons). Of this, 7.77 tons (6.94 long tons), or 33.85 per cent., ran off as drainage water.

The graphic representation of the results of the measurements made given in Fig. 31 shows that the amount running off, beginning with 26.7 gallons (101 l.) per hour, rose in the course of the first day to 34.3 gallons (130 l.) per hour, and then gradually diminished, and that the drainage was practically completed in 5 days. Measurements taken July 13 showed but 2.4 gallons (1 9.) per hour. Observations were continued until July 17. The last measurements showed 0.53 gallon (2.1) per hour.

Results.—Drainage was shown by this to play an important part in drying sludge. More than one-third of the water lost reached the place of measuring as drainage water. Draining was practically completed in the first half of the 8 days taken for drying.

The large, open drying bed was not adapted to the precise determination of the relation of draining to evaporation, as it was neither protected from rain, nor had it an absolutely impervious foundation; and as the amount of drainage water could not be directly measured, but had to be estimated from measurements taken several times daily, I therefore made experiments on a smaller scale with an apparatus which represented a fraction of an ideal drying bed.

Apparatus.—In a water-tight glass box holding 2.5 cu. ft. (71.7 l.) and provided with a faucet, was constructed a "filter-frame," consisting of slag, and resting on a grating; *i.e.*, pieces of slag were laid in 5 layers, each layer composed of finer fragments than the one below, so that the finer material would not fall through the interstices of the coarser layer below. The top layer was composed of washed Rhine sand 0.02 to 0.01 in. (1/2 to 1/4 mm.) in size. A wooden frame holding 1.05 cu. ft. (30 l.) covered with zinc, pressed firmly into the top layer, served to hold the sludge.

The experiments were conducted in a shed, protected from the rain.

Drainage Experiment II

On the 18th of July, 1907, 52.8 lbs. (24 kg.) of decomposed sludge from the experiment station were placed in the frame of the filter. The first of the drainage water appeared in 1 1/2 hours.

The whole amount of the water drained off was retained and measured every 24 hours. The results are given in Table IV, the first column showing the daily volume, and the second column the sum of the volumes up to the day given, the 3rd and 4th the same quantities in per cent. of the original amount of water contained in the sludge.

TABLE IV. (Condensed)

Date	Effluent				Percentage of the total amount of	
	For 24 hours		Total		47.972 lbs.	21.756 kg.
	Gallons	Cubic Centimeters	Gallons	Cubic Centimeters	For 24 hours	Total
July 19......	.511	1930	.511	1930	8.87	8.87
July 20......	.524	1980	1.035	3910	9.1	17.97
July 24......	.164	620	2.264	8550	2.85	39.15
Aug. 1.......	.004	15	2.719	10269	0.07	47.06
Aug. 2–7.....	.066	250	2.785	10519	1.25	48.31

The sludge became spadable in about 8 days. The course of drying was followed by the analysis of samples taken at intervals. A sample of the same sludge used in the experiment was preserved in an open water-tight tub and analyzed at the end of the period.

The results of the analyses at the beginning and end as well as the two between are given in the following table:

TABLE V.

Date	Water. Per cent.	Dried material. Per cent.		
		Total	Loss on ignition	Mineral residue
July 18..........	90.62	9.38	40.52	59.48
July 24..........	79.60	20.40	37.20	62.80
Aug. 1...........	69.19	30.81	35.50	64.50
Aug. 7...........	56.20	43.80	33.10	66.90
The sample left in the open tub showed the following composition:				
July 24..........	90.05	9.95	39.46	60.54

The drained sludge had been reduced in moisture from 90.62 per cent. to 56.20 per cent. In 6 days (July 24) it had been reduced to 79.6 per cent., while that in the tub, which lost only by evaporation, contained, after the same time and with equal depth, 90.05 per cent.

Drainage Water.—The results of an analysis of the drainage water are as follows

TABLE VI.

EXAMINATION OF WATER DRAINED OFF FROM JULY 27 TO AUGUST 1, CLEAR, COLORLESS, ODOR SLIGHTLY EARTHY.

	Parts per million =mg. per l.	
Residue from evaporation	2103	
Residue from ignition	1601	76.2 per cent.
Loss on ignition	502	23.8 per cent.
Oxygen consumed (according to Kubel)	221.6	$KMnO_4$ consumed.
Total nitrogen	99.4	
Of which: Organic nitrogen	2.8	
Nitrogen in ammonia	78.4	
Nitrogen in nitrates and nitrites (N_2O_3 and N_2O_5)	18.2	

When kept 10 days in a closed bottle at the temperature of the room no sulphuretted hydrogen was found.

Results.—The water originally contained was, according to the analysis, 5.747 gallons (21.756 l). The total volume of water removed can only be estimated in a round-about way as the samples taken for analysis during the test reduced the amount of sludge present. Without material error we may consider the amount of mineral matter 2.945 lbs. (1.336 kg.) unchanged and find, then, as the final weight of the drained sludge 7.54 lbs. (3.42 kg.) and of the moisture contained 4.240 lbs. (1.923 kg.).

We have, then:

Reduction of sludge .... 85.76 per cent.
Reduction of water .... 91.25 per cent.

There were drained off 2.682 gallons (10.159l).

=48.4 per cent. of the original volume of water.
=53.1 per cent. of the water removed.

According to this there were evaporated 20.537 lbs. (9.314 kg.) of water:

=42.8 per cent. of the original volume of water.
=46.9 per cent. of the water removed.

This experiment therefore confirmed the results of the first experiment and, moreover, showed that the decomposed sludge of the experimental plant loses under favorable conditions for draining, more than half of the water removed in this way. A further disintegration of the organic matter goes on during the drying. Odors are not perceptible (if the sludge is stored up in the open air without draining; decomposition is not nearly so energetic).

An analysis of the drainage water shows indications of biological purification (putrescibility, nitrates and nitrites) although the importance of this is lessened by the fact that the inference was drawn merely from a sample taken at the end of the experiment.

Comparative Experiments with Fresh and Decomposed Sludge

These experiments were made to ascertain whether there is any difference in the facility of drainage between fresh and decomposed sludge, and whether the superiority of our decomposed sludge in this respect is not due to the fact that the fresh sludge itself is exceptionally capable of being drained.

Top Layer of the Draining Bed.—In the following experiments coal waste was used as a top layer instead of pulverized slag, a material that was cheap to procure in the Emscher district. 92 per cent. of this covering material was composed of grains from 2 to 4 mm. in size, 8 per cent. from 1 to 2 mm.

This combustible material was used because of the intention to burn the sludge in some part of the Emscher district. In shoveling off the spadable sludge a portion of the top layer of the drying bed adheres to the sludge. If this top layer is combustible the calorific value of the sludge is increased; if not, it is reduced.

Porosity of the Draining Beds.—The draining beds were examined as to their porosity before the experiments were begun. Equal volumes of a preliminary dose of water were evenly flowed over the surfaces of the beds and the time and amount flowing off were noted. The porosity proved to be practically uniform as was to be expected with the similar construction of the beds. The beds were then allowed to dry for several days.

COMPARATIVE EXPERIMENTS WITH FRESH AND DECOMPOSED SLUDGE AT THE ESSEN EXPERIMENTAL PLANT.

The results of the analyses were:

Water	Dried material	Ash	Loss by ignition	
92.48%	7.52%	3.21%	4.31%	Fresh sludge.
Of the dried material	....	42.7 %	57.3 %	
89.44%	10.56%	6.13%	4.43%	Decomposed sludge.
Of the dried material	....	58.05%	41.95%	

Forty-four pounds (20 kg.) of each kind of sludge was brought to the draining beds. It was found that no comparison could be made in this way, as the fresh sludge drained off immediately through the beds, while the decomposed sludge, as usual, only permitted clear drainage water to pass. As the two kinds of sludge did not differ greatly as to the water contained, this was rather surprising. The decomposed sludge looked somewhat thicker than the other. As was seen later this was caused less by concentration than by the gas contained. Decomposed sludge which is full of gas bubbles becomes foamy and viscous.

It was thus impossible to compare the two sludges as to ease of draining.

Fresh sludge may be concentrated to a considerable degree, as a large part of the water rises in a fairly clear condition to the surface after standing awhile and can then be drawn off by a siphon. Such a process is advantageous in two respects. In the first place, it is probably possible in this way to drain the sludge without its running through, and secondly, it was possible to assume approximately equal amounts of moisture, which is of importance in considering the quantity of the run-off measured in the process of draining. A direct comparison of the time taken for drying had to be abandoned under the conditions, as the fresh sludge was favored by the removal of a part of its moisture.

Comparative Experiments with Fresh and Decomposed Sludge at the Rechlinghausen-Ost Plant

In order to place the work on a broader basis, sludge from another plant—that at Rechlinghausen-Ost[1]—was used, which was constructed on the principle of the Emscher tanks. This furnishes a more concentrated decomposed sludge in its well 23 ft. (7 m.) in depth than that from the experimental plant, 11 1/2 ft. (3.5 m.) deep, which was not originally built as an Emscher tank.

In order to experiment with samples containing, so far as possible, an equal amount of moisture, fresh sludge was allowed to settle; the supernatant water was siphoned off and the comparative experiments were begun. Analyses of the two kinds of sludge now showed that the desired equality of the contained waters had not been secured. The decomposed sludge contained 77.4 per cent. of moisture, about the average at that time (77.6 per cent.). The fresh sludge was not equally concentrated. The moisture (about 90 per cent.) had been reduced by siphoning but it still amounted to 80.35 per cent. Further examination showed that in other respects the compositions of the two kinds of sludge were not comparable, as the ash in the dried material of the fresh sludge was 57.2 per cent., while the decomposed sludge contained but 50.58 per cent.

Both differences were favorable to the fresh sludge, for wet sludge will give off more moisture, and sludge with less organic matter dries more easily.

In the experiment described the attempt to measure directly the loss in weight of sludge by draining had to be abandoned. As no attempt had been made to take intermediate samples, this was now done.

Execution of Comparative Experiments

Forty-four pounds (20 kg.) of each of the two kinds of sludge were again weighed and placed on the two draining beds.

The effluents from the draining beds were measured daily and analyzed from time to time. The beds themselves were also weighed at intervals—10 times in all. The results of measuring

[1] At time of operation in Feb., 1907, about 28,000 inhabitants provided for. 5400 cbm. per day. Six tanks 6 m. in diameter and 7 m. deep.

and weighing are shown graphically in Fig. 32. This shows the summation of the volumes of effluent and the loss of weight.

It shows how the fresh sludge which drained more quickly in the beginning on account of the large amount of moisture contained, was surpassed by the decomposed sludge on the second day. The difference increased up to the 4th day (April 29, 1908). Up to that time a thin layer of water rested on the surface of the fresh sludge. As the sludge underneath decreased in volume as the water was given off, contraction cracks appeared through which, in the two following days, the surface water could seep. The difference in the amounts of effluent was thus somewhat

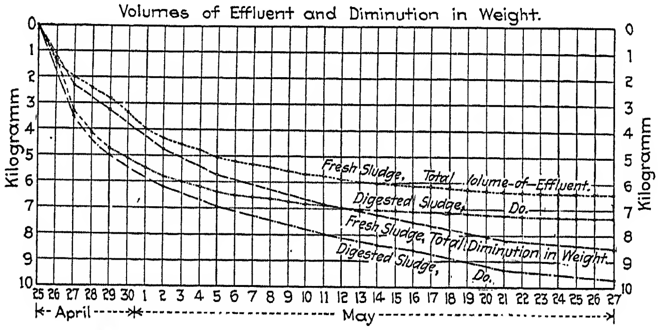

FIG. 32.—Drainage of fresh and decomposed sludge from the Recklinghausen–Ost clarification plant.

lessened. Although it decreased still more during the experiment, yet at the end it amounted to 0.24 gallons (0.911 l.). Only 40 per cent. of the original amount of fresh sludge appeared as drainage water to be measured, while of the decomposed sludge 47.4 per cent. appeared.

Results of Draining.—In spite of the greater amount of moisture, the fresh sludge gave up less water than decomposed sludge, even on this freshly prepared drying bed, *i.e.*, its drainage was inferior to that of the decomposed sludge. (As later experiments showed, the difference in practice is still greater, because the drying beds become clogged by the fresh sludge placed upon it. Decomposed sludge does not clog the beds.)

The curve showing the reduction in weight is similar to, but differs from the volume of the effluent in that it includes the reduction by evaporation and by gasification. Moreover, as the

latter is greater in the case of decomposed sludge, the difference is greater than it would otherwise be.

Examination of Drainage Water.—Results of the examination of the drainage water are given in Table VII. The effluents of the first, second and sixth days of fresh, as well as decomposed, sludge were examined and compared. Effluents of both kinds were found to be biologically pure—*i.e.*, they contained and produced no sulphuretted hydrogen, but did contain nitrates and nitrites.

The difference between the two was best shown in the residue on evaporation, and by its percentage of organic matter, which was much greater in fresh than in decomposed sludge. The oxidability, according to Kubel, shows the same thing.

Decomposed sludge therefore gives off drainage water of a more favorable composition than fresh sludge.

Drying.—Placing the beds under cover of a roof furnished an ideal condition for draining and for comparison but not for rapidity of drying. Although the deterring influence of rain was removed, evaporation was hindered by the lack of air and sunshine. The desired data for a comparison of the facility of draining was obtained but the time required for drying was greatly increased. Decomposed sludge became spadable in 16 days, which is a short time. Fresh sludge reached a similar consistency only after 33 days, although it had been artificially dried—more than twice as long as the other. After the fresh sludge had become firm, the experiment was concluded and the average samples were analyzed. Table VIII gives the results of the analyses from samples taken before beginning and after ending the experiment.

Results

A. *Fresh Sludge.*—We may conclude from the experiments that, for fresh sludge:

1. If it is brought without preliminary concentration to freshly prepared drying beds, it is possible that it may run through without being drained, even with a surface composed of grains 2 to 4 mm. in size.

2. If, as in the second experiment, the sludge has been concentrated (it contained only 80.35 per cent. moisture) it can be drained on freshly prepared beds. (Practically it has at this

TABLE VII

COMPARATIVE EXPERIMENTS WITH FRESH AND DECOMPOSED SLUDGE FROM THE RECKLINGHAUSEN-OST CLARIFICATION PLANT

Examination of Drainage Water[1]

	First day—Apr. 26, 1908		Second day—Apr. 27, 1908		Sixth day—May 1, 1908	
	Fresh	Decomposed	Fresh	Decomposed	Fresh	Decomposed
Volume of drainwater effluent.	1.405 l. .371 gal.	1.307 l. .345 gal.	0.586 l. .155 gal.	1.900 l. .502 gal.	0.650 l. .172 gal.	0.377 l. .100 gal.
Per cent. of original water contents in the sludge.	8.75	8.44	3.64	12.28	4.04	2.43
Per cent. of the total drainwater effluent.	21.85	17.80	8.68	25.9	10.01	5.13
Appearance..........	Slightly yellow. Milky and cloudy.	Slightly yellow. Opalescent.	Slightly yellow. Opalescent.	Very slightly yellow. Opalescent.	Deep orange. Very milky. Roily.	Colorless. Clear.
Odor................	Rather strong. Musty.	Slight. Musty.	Rather strong. Musty.	Very slight. Earthy.	Very musty.	Odorless.
Transparency........	2.9 cm. 1.1 in.	6.9 cm. 2.7 in.	10.5 cm. 4.1 in.	7.4 cm. 2.9 in.	1.6 cm. 0.6 in.	25.5 cm. 9.95 in.
Reaction............	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline	Alkaline
Residue on evaporation	3113 mg. 48 gr.	1877 mg. 28.9 gr.	2873 mg. 44.2 gr.	1617 mg. 24.9 gr.	3036 mg. 46.7 gr.	1624 mg. 25.0 gr.
Mineral...........	1986 mg. 30.6 gr.	1410 mg. 21.7 gr.	1943 mg. 30.0 gr.	1206 mg. 18.6 gr.	1950 mg. 30.1 gr.	1379 mg. 21.2 gr.
=per cent.........	63.2	75.2	67.7	74.6	64.3	84.7
Organic...........	1127 mg. 17.4 gr.	467 mg. 7.2 gr.	930 mg. 14.3 gr.	411 mg. 6.3 gr.	1068 mg. 16.4 gr.	245 mg. 3.8 gr.
=per cent.........	36.8	24.8	32.3	25.4	35.7	15.3
Suspended matter.....	Trace	Trace	Trace	Trace	Trace	Trace
Oxygen consumed....	448.7 mg. 6.9 gr.	256 mg. 3.9 gr.	347.6 mg. 5.4 gr.	195.9 mg. 3.0 gr.	391.8 mg. 6.0 gr.	214.9 mg. 3.3 gr.
Ammoniacal salts.....	Present.	Present.	Present.	Present.	Present.	Present.
Nitrites.............	Present.	Present.	Present.	Present.	Present.	Present.
Nitrates.............	Present.	Present.	Present.	Present.	Present.	Present.
Sulphuretted Hydrogen	0	0	0	0	0	0

1 All determinations are made with unfiltered water.

TABLE VIII

COMPARISON BETWEEN FRESH AND DECOMPOSED SLUDGE FROM THE RECKLINGHAUSEN-OST CLARIFICATION PLANT

Examination of Sludge

	Amount		Water		Solids		Ash		Organic matter	
	Kg.	Lbs.	Kg.	Lbs.	Kg.	Lbs.	Kg.	Lbs.	Kg.	Lbs.
Fresh Sludge, wet, April 25, 1908........	20	44.1	80.35 per cent. =16.07	35.4	19.65 per cent. =3.93	8.7	11.24 per cent. =2.24	4.9	8.41 per cent. =1.682	3.71
The same, drained, May 27, 1908........	11.43 from which may be deducted 1.2 water because it was left in the slag and weighed with it = 10.23	25.2 2.65 22.3	61.8 per cent. 6.32	13.9	38.2 per cent. 3.91	8.6	23.0 per cent. 2.248	4.97	15.2 per cent. 1.662	3.67
Reduction in 33 days........	9.77 = 48.9 per cent.	21.6	9.75 60.7 per cent.	21.5	0.02 0.51 per cent.	0.04	....	....	0.02 1.19 per cent.	0.04
Decomposed Sludge, wet, April 25, 1908.	20	44.1	77.4 per cent. 15.48	35.2	22.6 per cent. 4.52	9.95	11.42 per cent. 2.284	5.04	11.18 per cent. 2.236	4.93
The same, drained, May 27, 1908	10.28 from which may be deducted 1.28 water because it was left in the slag and weighed with it = 9.00	22.7 2.82 19.8	53.5 per cent. 4.815	11.2	46.5 per cent. 4.185	9.25	25.4 per cent. 2.284	5.04	21.1 per cent. 1.901	4.20
Reduction in 33 days	11.0 = 53.0 per cent.	24.2	10.665 69.0 per cent.	23.5	0.335 7.4 per cent.	0.74			0.335 15.1 per cent.	0.7

time no value; first, because it is not practicable to obtain large amounts of fresh sludge with much less than 90 per cent. moisture; secondly, because the draining beds become clogged after fresh sludge has been placed on them). As a rule also, it gives out an unbearable odor, noticeable at a long distance, after about 3 days.

3. Drainage water from fresh sludge becomes biologically pure after slowly percolating through the layer of slag, but still contains much organic matter in solution.

B. *Decomposed Sludge.*—The loss of water by draining decomposed sludge was 80.9 per cent. of the total loss of moisture, so that only 19.1 per cent. of that lost was evaporated.

C. *Comparison of Fresh and Decomposed Sludge.*—A comparison by draining the two kinds of sludge shows that:

1. Fresh sludge takes much longer to become spadable than decomposed sludge, even when it is at first partly de-watered (33 as compared with 16).

2. Fresh sludge gives off much less drainage water than decomposed sludge, even when it contains more moisture (47.45 per cent. as compared with 55.7 per cent.).

3. Drainage water from decomposed sludge contains less organic matter than from fresh sludge.

4. Decomposed sludge loses more organic matter by drainage than fresh sludge.

Deductions

Provision should be made for drainage in constructing drying beds for decomposed sludge. The drain pipes should be large enough to furnish an unobstructed flow for the large amounts of effluent at the beginning.

Drainage water from beds of fine slag requires no further treatment. It can be discharged into any stream.

The Reasons for Facility in Draining

The principal result of the experiments described was establishing the fact that decomposed sludge from Emscher tanks can be drained, *i.e.*, it dries in a short time by parting with a large part of the water which disappears (to 80 per cent.) through the porous bed. It remains to find out what characteristics are required to render drainage easy.

Viscosity.—The experiments with fresh and decomposed sludge furnished very important information. They showed that with a cover to the bed of uniform sized grains fresh sludge ran through, while decomposed sludge merely lost its moisture. The reason lies in the difference in concentration.

With fresh sludge only the coarsest ingredients remain on the drainage surface at first, owing to its fluid state, due to the large amount of contained water, while the finer material in part penetrates to a greater or less depth into the covering layer, some of it passing all the way through. The layer becomes more dense by the accumulation of the particles of sludge which penetrate the surface, no more passes through and at a certain depth an almost impenetrable mass is formed of the covering material and the particles of sludge which, when the second or third dose of sludge is applied may, under some circumstances, become so thick that it offers a strong resistance to the passage of water. There can then be no question of draining through so impervious a bed.

The more concentrated septic sludge and the thick-flowing digested sludge of Emscher tanks, on the contrary, do not pass through the filtering layers, but give off their water.

Destruction of Colloids.—According to the results of the second experiment Emscher sludge drained more rapidly than artificially concentrated fresh sludge from the same plant. This is due largely to the fact that the colloids in the fresh sludge are partially destroyed (in digested sludge—Trans.). Presumably the decomposition caused by bacteria and enzymes which attack the organic material on the surface, is most apparent in the sponge-like hydrogels filled with liquid with their enormously large surfaces. The destruction of these diminishes their property of holding water. As the sludge loses moisture it drains more easily.

Destruction of Organic Matter.—The destruction of organic matter, such as fragments of animals and plants, which are found in the sewage from kitchen, garden and slaughter house wastes, takes place in the same way. These substances, which bind, and from the beginning contain, much water, are found only in very small quantities in decomposed sludge.

The difference in the water content between fresh and decomposed sludge shows how far the destruction of the water binding colloids and organic matter has progressed. As compared with 90 to 95 per cent. moisture in fresh sludge, I found, *e.g.*, in

Emscher sludge from the Recklinghausen plant an average of 79.3 per cent., in sludge from the Essen-N. W. plant only 75.6 per cent. Occasionally liquid sludge is obtained from Emscher tanks with nearly as little as 70 per cent. moisture, a concentration equal to the spadable sludge from centrifugal machines. On the 8th of April, 1909, in an average sample of 123.58 cu. yds. (94.34 cbm.) of wet sludge drawn off under water, from the Essen-N. W. plant, *e.g.*, I found 71.9 per cent. moisture; from another taken May 8, 1909, of 85.1 cu. yds. (65.0 cbm.), 71.35 per cent. moisture, while, according to examinations made at the Royal Experimental Station for Water Supply and Sewage Disposal[1], the spadable centrifuged sludge from Harburg contained between 69.7 and 74.2 per cent. moisture, an average of 72.5 per cent. A sample taken by me at Harburg in 1908 showed 68.8 per cent. In Frankfort the fresh centrifuged sludge contained about 70 per cent. moisture (according to data furnished me there in 1908).

The destruction of water binding substances is shown also when in a spadable condition.

Thus I found in 4 samples of Emscher sludge at Recklinghausen-Ost which had just become spadable, an average of 58.27 per cent., in 13 samples from Essen-N. W. an average of 52.34 per cent.

We may thus assume for spadable fresh sludge about 71 per cent. moisture, for spadable decomposed sludge about 55 per cent.

Gas Contained.—The ability of decomposed sludge to drain is materially assisted by the gas contained. As already mentioned, large quantities of gas are formed by the decomposition of sludge in Emscher tanks, which consists mainly (about 3/4) of methane and (about 1/4) of carbonic acid. These gases pass off as soon as large bubbles are formed from the original minute ones, as the former overcome the pressure of the overlying layer of sludge. A large volume of gas at one point is necessary to effect this. The bubbles remain in the viscous material until this occurs. At the greatest depth, about 33 ft. (10 m.) the gases are under a pressure of one atmosphere. If sludge is drawn off it comes filled with compressed gas. With the release of pressure from this greater depth the volume of the bubbles increases, increasing

[1] Reichle and Thiesing "Mitteilung aus der Kgl. Prüf-Anst. für Wasserv. und Abwässerbeseitigung," No. 10.

the volume of the sludge. This, being full of these gas bubbles, is changed into a foaming mass. The increase in volume renders drainage more easy. The tendency to penetrate the surface layer of the beds is reduced. The water in the sludge passes through the channels formed by the disappearing gas, seeps down and drains off. If sludge freshly drawn from an Emscher tank is allowed to stand in a glass cylinder (which may be considered an impervious sludge bed) bubbles of gas may be seen on the sides which gradually increase in number and size. The volume then increases and a layer of clear water forms at the bottom. The volume of sludge above the water is not reduced as

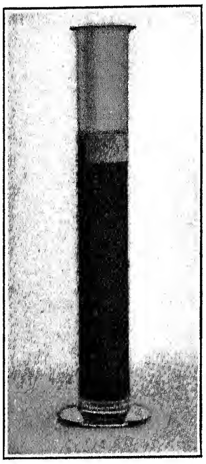

Fig. 33.

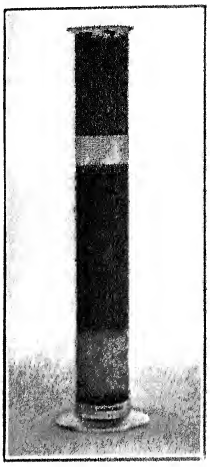

Fig. 34.

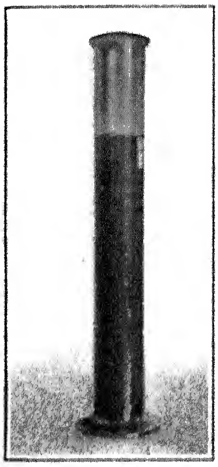

Fig. 35.

it has a foamy structure, *i.e.*, it contains a great number of small and large compartments filled with gas bubbles. This foamy material, being lighter than water, is forced up by the water which settles to the bottom. It also spreads as the gas increases in volume. The volume of the whole is thus increased by more than that of the water at the bottom.

Figs. 33 and 34 illustrate the process. The original height of the sludge is indicated by the upper edge of the strip of paper. The second cylinder shows how the water has settled after 24 hours and the entire volume is increased. The thin layer of sludge at the bottom is composed of heavy particles which are deposited later, as shown by the solid particles just sinking.

This method increases the ease of drainage appreciably. The water can filter through unhindered as it reaches the porous covering containing no sludge.

Fresh sludge is just the reverse in this respect. The water does not sink, but rises. Fig. 35 represents fresh sludge from the clarification plant at Essen 24 hours after being placed in the cylinder. The upper edge of the paper indicates again the original surface of the sludge. It can be seen that the sludge has not risen and that dirty water is on the top.

In order to show to what extent the enclosed gases cause these phenomena in decomposed sludge and whether a subsequent evolution of gas assists, I experimented with a sample of sludge from Essen-N. W. by warming a portion of it for two hours at 99° F. (37° C.), and stirring it frequently to remove the larger gas bubbles and then removing the gas as much as possible by subjecting it to the vacuum produced by a good ejector while shaking it frequently. The sludge sample so treated and another without having the gas removed were allowed to stand 24 hours with as uniform a temperature as possible.

The original amount and the increase in volume and the settled water were measured.

TABLE IX

SLUDGE FROM TANK NO. 5 OF THE ESSEN-N. W. PLANT

	1. In original condition		2. With gas removed	
	Gals.	c.c.	Gals.	c.c.
Quantity at beginning of experiment.	0.1096	415[1]	0.0832	315
After 24 hours	0.1400	530	0.0937	355[2]
Increase in volume	0.0304	115	0.0105	40
Same in per cent. of original amount	27.7 below.		12.7 above.	
Water separated	0.0105	40	0.0040	15
Same in per cent. of original amount.	9.64		4.76[3]	

The temperature at the beginning was 60.8° F. (16.0° C.) and at the end 59.9° F. (15.5° C.).

[1] 425 in original. [2] 455 in original. [3] 4.3 in original. The foregoing alterations made to secure consistent results as the original figures are erroneous. Tr.

It is an astonishing fact that in spite of the gas removed there was a perceptible increase in volume, although this was not quite half so large as before. It is possible, either that the gas was not entirely removed and that a thicker more watery layer had accumulated in the lower part of the sludge, forcing up the lighter parts, or else that, on account of the action of bacteria and enzymes on the sludge, there was a further development of gas, thus increasing the volume. Probably both these views are true.

Experience in Methods of Draining at Large Plants

These experiments show that with proper preliminary treatment (decomposition under water in deep tanks) sludge on drained drying beds may be easily separated into a spadable earthy material and a harmless liquid which has the characteristics of an effluent from contact beds. These experiments, although successful on a small scale, do not solve the question as to the applicability of this method to a large plant.

Drying sludge by draining has been practised on a large scale at Recklinghausen-Ost (28,000 inhabitants), Essen-N. W. (60,000 inhabitants) and Bochum (130,000 inhabitants), as well as at several smaller plants. The results have been much more favorable than was anticipated. Much material is available regarding the results of drying at the more accessible of the two large plants, that at Essen-N. W., collected by operating engineer Blunk, in so far as it relates to the measurement of the depth of sludge and the time of drying, in connecteon with estimates for the contractors for the removal of the sludge authorized by the Emscher Association. These measurements have been shown in diagrams (not reproduced). The rainfall was measured by Mr. Winter, Municipal Superintendent of Clarification, at the Essen plant.

Description of Drying Beds.—The drying bed at Essen-N. W. for sludge taken from a tank 29.5 ft. (9 m.) deep lies several meters below the surface of the ground and is artificially drained by an underground conduit laid parallel with the stream to which it empties, and has an outlet below a dam. The bed is supplied with drain pipes laid end to end, at intervals of 8.2 to 9.8 ft. (2.5 to 3 m.). These lead to an open ditch surrounding the bed. Above the pipes is a layer of furnace slag 12 in. (30 cm.) thick, and above this a layer of crushed slag 8-10 in. (2 cm.)

thick. (Coke cinders are sometimes used in place of the latter, as they are often cheaper). In recent plants having a sand catcher the grit taken from this is used. As this contains no floating particles it need only be placed in thin layers.

The drying bed is divided longitudinally by planks into 3 parts, numbered I, II and III. They are 3465, 3411 and 3153 sq. ft. (322, 317, and 293 sq. m.) in size. Each has, along the middle, rails supported by piles for carrying the sludge away. The plant began operation in December, 1908. Sludge was placed on beds I and III April 8, 1909, and on bed II April 10, 1909. In a short time (3 to 5 days) it became spadable, but was not removed from the beds until April 19, 1909. (Time of retention 9 to 11 days.)

Note by Translator

In the conclusions drawn from these experiments no consideration has been given to these first drainings, as it could not be determined definitely when the sludge became spadable. The results that were reached cover the period of a full year, ending May 1, 1910.

The septic sludge received by the drying beds was as follows:

Month, 1909	Bed number							
	I		II		III		Total	
	Cu. yds.	Cbm.	Cu. yds.	Cbm.	Cu. yds.	Cbm.	Cu. yds.	Cbm.
May	355.3	271.6	424.1	324.2	360.4	275.5	1139.8	871.3
June	358.1	273.8	264.8	202.4	337.3	257.9	960.2	734.1
July	271.7	207.7	201.2	153.8	175.5	134.2	648.4	495.7
August	278.1	212.6	337.2	257.8	326.5	249.6	941.8	720.0

The total for June, July and August was about 2550 cu. yds. (1950 cbm.) in 92 days, giving an average of 27.7 cu. yds. (21.2 cbm.) of septic sludge per day containing about 80 per cent. moisture.

According to Spillner and Blunk[1] the mean daily flow of sewage to the Essen-N. W. plant was, at the time under consideration (1909–10), as follows:

[1] Tech. Gemeind., Vol. XIII (1910).

Sewage from 60,000 persons...	2.77½	mil. gal.	=10,500	cbm.	=32.0%
Wastes from Krupp's works...	9.51	mil. gal.	=36,000	cbm.	=63.7%
Mine drainage..............	0.26½	mil. gal.	= 1000	cbm.	} = 4.3%
Coal washing water..........	0.13	mil. gal.	= 500	cbm.	}
Total[1]...................	12.68	mil. gal.	=48,000	cbm.	=100.0%

If we assume this volume equivalent to that derived from a population of 65,000, we have:

Volume of sewage per capita daily.......	194.8 gallons	=738	lit.
Volume of wet sludge per thousand persons daily..............................	.426 cu. yds.	=	.326 cbm.
Volume of wet sludge per million gallons sewage............................	2.19 cu. yds.		
Volume of wet sludge per cubic meter sewage,		=	.442 lit.

The results of operation show that the expectations from the methods adopted for drainage have been realized. In spite of an unusually wet year, sludge averaging 9 in. (23 cm.) in depth, became spadable in 5.87 days. Sometimes, in dry weather, it dried in 2 days, as May 11 (III) and May 20 (II); in September sometimes in one day.

In the 365 days under consideration, the drying beds were:

I	Occupied 236 days	Empty 129 days.
II	Occupied 246 days	Empty 119 days.
III	Occupied 294 days	Empty 81 days.

These figures show that the beds were not completely utilized although their area was but about 9684 sq. ft. (900 sq. m.), making, for a population of 60,000, only 0.161 sq. ft. (0.015 sq. m.) per capita. The tables show, moreover, that sludge is seldom removed in winter. As it takes longer to decompose and to dry in winter than in summer, care was taken to provide as much storage capacity as possible in the deep sludge chambers in winter. In this way one is independent of the weather, as it is only necessary to discharge small quantities of sludge, and these at long intervals.

Table X shows the changes which sludge undergoes in draining. The amount was reduced 45 to 58 per cent. in weight, 60 to 77 per cent. in moisture and 0.1 to 0.9 per cent. in dried material.

[1] The Krupp wastes contain the sewage and water used in lavatories from about 10,000 workmen. The sewers are on the combined system. The disposal works consist of two grit chambers, one coarse screen and nine Emscher tanks. These were built in 1907–8 and put in operation November, 1908.

TABLE X

ESSEN-NORDWEST CLARIFICATION PLANT. CHANGES IN SLUDGE BY DRAINAGE

Experiment	Date, 1909	Wet sludge: Amount	Wet sludge: Water	Wet sludge: Dried material	In dried material: Organic	In dried material: Mineral	Decrease: Amount	Decrease: Water	Decrease: Dried material
A........	May 25, Bed II, Depth 6.6 in. 17.0 cm.	70.6 c.y., 54.0 cbm. Spec. gr. 1.0927 66.1 tons 59.01 t.	78.67% 51.98 tons 46.41 t.	21.33% 14.1 tons 12.6 t.	57.53% 8.12 tons 7.25 t.	42.47% 5.99 tons 5.35 t.	57.52% 38.01 tons 33.94 t.	72.87% 37.88 tons 33.82 t.	0.95% 0.13 tons 0.12 t.
B........	May 29, Bed II, Depth 7.4 in. 19.0 cm.	78.7 c.y., 60.2 cbm. Spec. gr. 1.244 83.9 tons 74.9 t.	78.74% 66.05 tons 58.97 t.	21.26% 17.84 tons 15.93 t.	58.2% 10.38 tons 9.27 t.	41.8% 7.46 tons 6.66 t.	62.67% 52.57 tons 46.94 t.	77.38% 51.11 tons 45.63 t.	0.82% 1.47 tons 1.31 t.
C........	June 6, Bed I, Depth 8.0 in. 20.5 cm.	86.34 c.y., 66.09 cbm. Spec. gr., 1.1157 82.5 tons 73.7 t.	72.24% 59.63 tons 53.24 t.	27.76% 22.92 tons 20.46 t.	60.7% 13.91 tons 12.42 t.	39.3% 9.01 tons 8.04 t.	49.86% 41.16 tons 36.75 t.	66.0% 39.36 tons 35.14 t.	0.79% 1.80 tons 1.61 t.
D........	July 5, Bed III, Depth 8.9 in. 22.8 cm.	87.4 c.y., 66.8 cbm. Spec. gr. 1.095 81.9 tons 73.14 t..	81.32% 66.62 tons 59.48 t.	18.68% 15.30 tons 13.66 t.	46.41% 7.11 tons 6.35 t.	53.51% 8.19 tons 7.31 t.	58.41% 47.85 tons 42.72 t.	71.79% 47.8 tons 42.7 t.	0.15% 0.022 tons 0.02 t.
E........	Aug. 2, Bed II, Depth 7.6 in. 19.4 cm.	80.4 c.y., 61.5 cbm. Spec. gr., 1.223 84.3 tons 75.25 t.	74.1% 62.44 tons 55.75 t.	25.9% 21.84 tons 19.5 t.	52.4% 11.45 tons 10.22 t.	47.6% 10.39 tons 9.28 t.	45.31% 38.2 tons 34.1 t.	60.9% 38.0 tons 33.9 t.	0.26% 0.22 tons 0.2 t.

TABLE X.—*Continued*

ESSEN-NORDWEST CLARIFICATION PLANT. CHANGES IN SLUDGE BY DRAINAGE

Experiment	Rainfall			Spadable sludge				
	Depth	Amount	Date, 1909	Amount	Water	Dried material	In dried material	
							Organic	Mineral
A	0.29 in.	3.1 c.y.	May 28. Time of drying 3 days.		50.23%	49.77%	57.14%	42.86%
	7.5 mm.	2.4 cbm.		28.08 tons	14.10 tons	13.98 tons	7.99 tons	5.99 tons
				25.07 t.	12.59 t.	12.48 t.	7.13 t.	5.35 t.
B	0.14 in.	1.6 c.y.	June 2 Time of drying 5 days.		47.71%	52.29%	54.46%	45.54%
				31.32 tons	14.94 tons	16.37 tons	8.92 tons	7.46 tons
	3.7 mm.	1.2 cbm.		27.96 t.	13.34 t.	14.62 t.	7.96 t.	6.66 t.
C	0.45 in.	4.8 c.y.	June 19 Time of drying 7 days.		48.98%	51.02%	57.35%	42.65%
				41.39 tons	20.3 tons	21.11 tons	12.10 tons	9.01 tons
	11.5 mm.	3.7 cbm.		36.93 t.	18.1 t.	18.83 t.	10.81 t.	8.04 t.
D	2.24 in.	22.0 c.y.	July 10 Time of drying 5 days.		55.16%	44.84%	46.41%	53.59%
				34.07 tons	18.79 tons	15.28 tons	7.09 tons	8.19 tons
	57.4 mm.	16.8 cbm.		30.42 t.	16.78 t.	13.64 t.	6.33 t.	7.31 t.
E	0.98 in.	10.3 c.y.	Aug. 7 Time of drying 5 days.		53.1%	46.9%	51.96%	48.04%
				46.09 tons	24.47 tons	21.6 tons	11.22 tons	10.39 tons
	25.0 mm.	7.9 cbm.		41.15 t.	21.85 t.	19.3 t.	10.02 t.	9.28 t.

Thirteen analyses gave an average of 52.3 per cent. moisture in spadable sludge.

Drainage Water.—Drainage water, of which several samples were taken, showed the same favorable characteristics as in the experiments described.

24-*Hour Samples.*—In order to avoid any accidental errors in sampling and in order to show the changing composition of the drainage water in the course of the experiment, continuous average samples were taken on August 12 and 13, 1909. The samples, which were taken hourly from all of the 15 effluent drains, were mixed together for each 3-hour sample and examined. The result of these analyses is given in Table XI.

TABLE XI

ESSEN-NORDWEST CLARIFICATION PLANT

Drainage Water, August 12 and 13, 1909, from Bed III

Time	10.15 to 1.15	1.15 to 4.15	4.15 to 7.15	7.15 to 10.15	10.15 to 1.15	1.15 to 4.15	4.15 to 7.15	7.15 to 10.15
Gallons per period[1]	296.0	193.2	186.4	164.9	142.7	123.0	88.9	83.7
Liters per period[1]	1,120.4	731.4	705.5	624.0	540.7	465.6	336.6	316.7
			Parts per Million = Mg per liter					
Residue on evaporation	2,713.5	2,831.5	2,935.5	3,012.0	2,863.0	2,713.0	2,612.5	2,560.0
Residue on ignition	2,298.5	2,440.5	2,491.5	2,578.5	2,557.5	2,427.5	2,286.5	2,229.0
Loss on ignition	415.0	391.0	444.0	433.5	305.5	285.5	326.0	331.0
Chlorine	426.0	488.0	520.0	544.0	556.0	560.0	556.0	540.0
Nitrogen, total	47.6	47.6	53.2	47.6	49.7	51.8	51.8	49.0
Nitrogen, as H_4N	21.0	23.8	23.1	24.5	30.1	35.0	36.4	33.6
Organic nitrogen	0.7	1.4	3.5	1.4	2.8	2.1	0.7	1.4
N in nitrates and nitrites	25.9	22.4	26.6	21.7	16.8	14.7	14.7	14.0
Suspended matter, total	79.6	91.0	69.6	44.4	46.2	57.8	194.2	159.6
Mineral	53.0	64.8	50.0	27.8	31.8	41.6	145.4	116.8
Organic	26.6	26.2	19.6	16.6	14.4	16.2	48.8	42.8
Putrescibility 10 days storage in closed flask.	Not putresc.	Not putresc.	Not putresc.	Not putresc.	Not putresc.	Not putresc.	Not putresc.	Not putresc.

It shows that the drainage water meets the demands of a biologically pure water, for the nitrogen is almost entirely mineralized and the liquids show no signs of putrefaction (H_2S reaction) even when kept for 10 days in a closed bottle.

[1] The word "Stunde" is taken to mean *period* rather than *hour*.—Tr.

Drainage, therefore, fulfills all expectations from the experiments as to time of drying and composition. It is employed at the six plants now in operation in the Emscher District.

Removal of Drained Sludge.—At one of these plants (Recklinghausen-Ost) the drained sludge is sold as a fertilizer to the farmers at 12 cts. (50 pfg.) per cartload (at the dumping ground). In the 3 years during which this plant has been in operation, the demand has exceeded the supply, so that the sludge is usually sold long before it is prepared.

When no farming is carried on in the neighborhood, drained sludge is used for filling in land. It is particularly well adapted to this as it does not soften with the rain and is so firm that large deposits of it can be walked on without sinking.

At Essen-Nord, which was built this year, attempts will be made to dry the drained sludge from 180,000 inhabitants in furnaces, similar to those used for the incineration of street sweepings.

In the 15 plants to be built this year in the Emscher District, draining beds for drying the sludge have been planned and are, in part, constructed.

RESULTS OF THE OPERATION OF SOME OF THE MECHANICAL SEWAGE CLARIFICATION PLANTS OF THE EMSCHER ASSOCIATION

BY

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CHEMIST

AND

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TRANSLATED BY

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INTRODUCTORY NOTE

The foregoing paper by Dr.-Ing. Spillner presents in a compact form the results arrived at by the Emscher Association in the operation of the type of sedimentation tank devised by Dr. Ing. Imhoff for the Association up to the end of 1909. The viewpoint taken is, naturally, that of the scientist, and the conclusions drawn are largely from chemical and physical tests of samples taken during the operation of the several treatment plants.

This paper is now very appropriately supplemented by one bringing the subject up to the present year written by Dr.-Ing. Spillner in conjunction with Mr. Blunk, the engineer in charge of operation. This, therefore, not only has the advantage of a longer experience with this mode of treating sewage, and of the various comments and criticisms concerning the Emscher tank that have been made during the past year or two and which are, in effect, answered in this way, but of the additional opinions formed by one intimately connected with the plants in their varying conditions of actual operation.

More or less matter in the original text is, almost necessarily, a repetition in new form of what was contained in Spillner's original paper. So far as consistent with the proper form and interpretation of this later work such matter has been omitted in the translation, the reader being referred to the earlier paper.

K. A.

RESULTS OF THE OPERATION OF SOME OF THE MECHANICAL SEWAGE CLARIFICATION PLANTS OF THE EMSCHER ASSOCIATION.

Measurements of the Sludge

The quantity of sludge contained in each tank of the sewage clarification plants at Essen, Recklinghausen and Bochum was measured at intervals of ten days in order to control properly the treatment of the sludge. These measurements were made by sounding with a thin sheet iron plate, as the surface of the sludge is always horizontal and compact or dense enough to sustain the weight of the light plate. In this way the depth of the superincumbent liquid was readily determined, and thence also the volume occupied by the sludge. Any decrease in this depth represents a corresponding increase in the volume of sludge. The quantity of water contained in the sludge varies at different depths in the mass, but the error in measurement caused thereby is balanced in the successive observations, as the proportion is approximately constant. These soundings are entered in a special book, and the corresponding volumes of sludge are subsequently computed and recorded in the office.

For convenience of inspection the records are also kept in diagram form, with the ordinates representing the total quantity of sludge deposited and the abscissas the number of days elapsed from the outset. The discharge of sludge from each tank is similarly recorded and shown on the diagram. By properly connecting the successive points thus located, the diagram for each plant will exhibit two more or less irregular lines, of which the upper one shows by scale the total volume of sludge deposited, while the lower one shows the total volume of sludge discharged, since the day that the plant was put in operation; and the volume of sludge contained in the tanks at any time will be represented by the difference between the ordinates of the upper and lower line for that time or day. The diagram

also enables us to determine approximately how long the sludge which was removed remained in the tank. This is done by simply moving to the left the ordinate of the lower line until it coincides with the equal ordinate of the upper line, and noting the corresponding interval on the axis of abscissas which shows the number of days. Several such diagrams are given in the paper, but with one exception are here omitted.

For example, the diagram for the Recklinghausen plant shows that on April 20, 1909, the total deposit of sludge was 2609 cu. yds. (1995 cbm.), and that on the same day 59 cu. yds. (45 cbm.) were discharged, the total previous discharge having

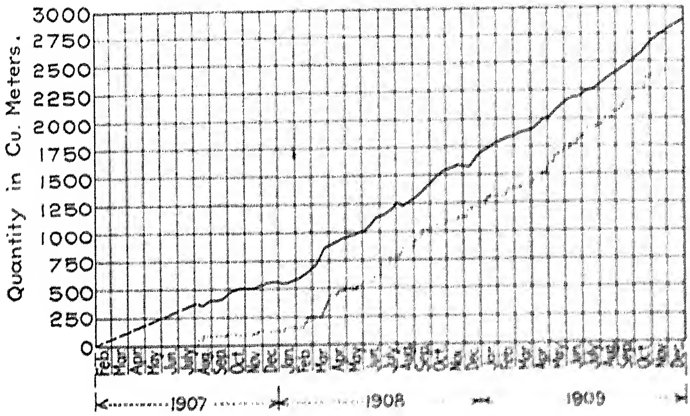

FIG. 36.—Diagram showing increase of sludge in the Recklinghausen Ost Clarification Plant

The upper line represents the aggregate volume of sludge deposited and the lower line represents the aggregate volume of sludge discharged

been 1910 cu. yds. (1460 cbm.); hence on this day the aggregate discharge was 1910 + 59 = 1969 cu. yds. (1505 cbm.). By moving this ordinate to the left until it intersects the upper line representing the total sludge deposited, it will be found that this intersection corresponds on the axis of abscissas to Oct. 17, 1908, thus indicating that the sludge which was removed on April 20, 1909, had remained in the tank for a period of six months. In reality, however, the period of detention in the tank is considerably less, as the sludge does not descend or move at a uniform rate from the surface to the mouth of the discharge pipe in the sump at the bottom of the tank.

Before and after any sludge is discharged from a tank, the position of its surface is always carefully noted by soundings, as above described. The difference between these two measurements gives the quantity removed, which is checked by measuring the depth of the mass at a number of places upon the level drying bed or filter. If made quickly, or before an appreciable quantity of water escapes into the underdrains of the bed, the two measurements agree closely.

The amount of water in the discharged sludge varies with the depth of the tank and the age and chemical composition of the sludge. As will be shown subsequently, it contains on the average about 75 per cent. of water as it leaves the tank; and after being allowed to drain for a few days upon the drying beds, the quantity of moisture reduces to 52 per cent. at Essen N. W. and 65 per cent. at Recklinghausen, or to 58 per cent. on the average. By this drainage the volume of the sludge is reduced about 40 per cent., and it then becomes consistent enough to be spadable, or to be cut and handled with a shovel

The authors exhibit in diagram form the results attained with the sludge of the Essen-N. W. plant for the year from April 1, 1909, to April 1, 1910. There are three separate sludge draining beds, and the observations relating to them during this period are shown graphically. The several lines indicate the date and quantity of sludge discharged, and the subsequent date and volume when the sludge had become spadable and was removed from the drying bed; also the depth of the rainfall and the date of its occurrence. When first taken from the tanks the sludge contained from 72 to 75 per cent. water, and when finally carried away from the beds it contained from 55 to 60 per cent. water. The abscissas indicate the number of days required for the sludge to become dry enough to handle with a shovel. Thus on October 6, 1909, 95.6 cu. yds. (73 cbm.) of liquid sludge was discharged upon bed No. I, and only three days later it was found to be spadable, its volume having reduced to 53.1 cu. yds. (40.5 cbm.). In this short period the shrinkage in volume was 42.5 cu. yds. (32.5 cbm.) or 44.5 per cent.

Another diagram shows the accumulated volumes of liquid and drained sludge during the twelve months mentioned, each by a continuous line or curve. It shows that during this time 7194 cu. yds. (5500 cbm.) of liquid sludge had been discharged from the tanks, and that this volume had been reduced by drainage

to 4709 cu. yds. (3600 cbm.), thus making the average shrinkage in volume 35 per cent. The preceding diagrams also indicate a large variation in the time required for the sludge to become spadable, but the reason therefor becomes evident on comparing these periods with the corresponding rainfall. Thus on July 13 and 14, 1909, all of the beds had been filled with sludge, and in the afternoon of the fourteenth, an excessive rainfall occurred that yielded a depth of 1.34 in., and by the failure of an embankment caused the sludge beds to become covered with water to a depth of 8 in. In consequence of this accident the sludge in one of the beds did not become spadable until July 27, a period of 14 days, although a much shorter time sufficed in the other beds. Such cases, however, are exceptional, and the average period, including rainy weather, is from 6 to 7 days.

In dry summer weather, the drainage or drying is frequently accomplished in two or three days, while in severe winter weather a somewhat longer time is required, as the water in the sludge may then freeze. This freezing is troublesome, as the sludge after thawing is not only rendered nearly as wet as it was originally, but is also deprived of its contents of gases upon which the facility for quick drainage depends in high degree. This peculiar property was fully pointed out in a paper by Dr. Imhoff, in *Technisches Gemeindeblatt*, October 5, 1910, pp. 193–199. In consequence of the escape of the gases while the frozen mass is thawing, the wet sludge settles upon the surface of the bed, thereby causing it to become clogged and compelling the water to rise to the top of the liquid mass, as in the case of freshly deposited sludge. For this reason it becomes expedient to discharge but little sludge in winter, and to make the utmost use of the storage capacity in the septic chambers of the deep tanks by withdrawing therefrom as much sludge as possible while the weather is favorable in the summer and autumn.

The sludge beds of the Essen-N. W. plant have an area of 1077 sq. yds., and in the said period of twelve months they drained a volume of 5500 cbm., or 7195 cu. yds., of liquid sludge. This is at the rate of 6.68 cu. yds. per square yard of surface per year, which represents a depth of 20.04 ft. on the entire surface. The liquid sludge was deposited on the beds to a depth of from 8 to 10 in. at each application, thus requiring about 27 or 28 applications per year in order to drain the stated volume; and as the average period of time required for drainage is about 6 days to each

application, it follows that the sludge beds must be in active use for an aggregate of $6 \times 28 = 168$ days per year. This computation shows that in the climate of Essen ample time is available during the year for the repeated fillings, clearings and repairs of the sludge beds after due allowance for freezing weather in winter.

At all the other plants of the Emscher Association, the experience with the sewage sludge is similar to that at Essen-N. W., as described above. It should also be mentioned that at Recklinghausen, Holzwickede and the colony at the Count Schwerin Mine, the drained sludge is taken away by neighboring farmers, while at Essen and Bochum, where little agriculture is carried on, it must be used for filling depressions and low places. [The populations tributary to the Recklinghausen, Holzwickede and mine colony plants are respectively 30,000, 3200 and 3100, while those tributary to the Essen-N. W. and Bochum plants are respectively 60,000 and 145,000. The aggregate dry-weather flow of sewage at the first three plants is about 2,460,000 U. S. gallons per day, while at the last two plants it is about 25,910,000 U. S. gallons per day and contains much mine drainage and ground water. The quantities of sludge produced annually at each plant are not given, but it is obvious that only a small proportion of the drained sludge finds agricultural utilization. Trans.]

It is of much interest to compare the volume of the fresh sludge, as it is deposited in the settling chamber or upper portion of an Emscher tank, with that of the decomposed liquid sludge discharged from the bottom of the septic chamber, and also to determine how much of the original volume is left after the septic sludge has been drained or dried until it attains a consistency like that of moist earth which can be cut and handled with a shovel. Let us assume that the fresh sludge contains 95 per cent. water. After remaining for several weeks in the septic chamber, it will contain only 75 per cent. water, and about one-third of the original quantity of organic matter will have been gasified. In 100 cbm. of fresh sludge there will accordingly be 5 cbm. of dry solid matter, of which 65 per cent. on the average, or 3.25 cbm., will be organic matter. Since one-third of this latter substance, or 1.08 cbm., becomes gasified, the remainder will be $(3.25 - 1.08) = 2.17$ cbm. of organic matter. The mineral matter amounts to $5 \times 0.35 = 1.75$ cbm., and hence the original

volume of 5 cbm. of dry solid matter is reduced to $(2.17 + 1.75) = 3.92$ cbm., of which 55 per cent. is organic and 45 per cent. mineral matter. The septic sludge, however, contains 75 per cent. water; hence with this addition of water the 3.92 cbm. of resultant dry solid matter will have a volume of $3.92 \times 4 = 15.68$ cbm. The original volume of 100 cbm. of fresh sludge has thus reduced to a volume of 15.7 cbm. of the liquid septic sludge yielded by an Emscher tank. This represents a shrinkage in volume of about 84 per cent.

Furthermore, this liquid septic sludge shrinks about 40 per cent. in volume by drainage upon the beds to a spadable consistency. Its volume in the aforesaid case is thus reduced to $15.7 \times 0.6 = 9.4$ cbm., and hence we have a total reduction in volume of $(100 - 9.4) = 90.6$ cbm., or nearly 91 per cent., of the original volume of 100 cbm. of freshly deposited sludge.

Examination of the Liquid Sludge

The data given in the tables refer to average samples of the sludge. In collecting samples for examination, a small portion of the liquid is taken at regular intervals during the period of discharge as it flows in the open trough on its way to the sludge bed, and by mixing together all these portions an average sample is obtained. These average samples are placed in tightly closed jars and brought to the laboratory, where they are usually examined on the same day. The examination generally embraces the following determinations: 1. The external peculiarities and smell; 2. the amounts of contained water and dry matter; 3. the proportions of organic and mineral substance in the dry matter; 4. amount of total nitrogen in the dry matter; 5. reaction, alkaline or acid; 6. amount of fat in the dry matter; 7. amount of gas-making matter and fixed carbon, by coking; 8. amount of silica, iron and alumina in the ash.

The results of a number of such sludge analyses are given on pages of Spillner's paper on "The Drying of Sludge." These data are now supplemented by the tables given in the present paper.

The sludge that is decomposed in the deep Emscher tanks is very black in color, and has the consistency of a more or less thick gruel. It is usually quite liquid, and flows easily in a trough. In this state it is difficult for the unaided eye to

recognize the nature of its various components. Its reaction is always slightly alkaline. It has a faint odor of india-rubber or tar, even in localities where the liquid wastes of coke and gas works are not admitted into the sewers. This tarry odor is due to the activity of certain micro-organisms, and is also found in well-decomposed river mud and the sludge from other well-ripened septic tanks. It is always faint, and can be detected only in the immediate vicinity of the mass; hence it cannot pollute the atmosphere sufficiently to be regarded as a nuisance if the sludge is properly decomposed. Every Emscher or other septic tank, however, requires a certain period of time after being placed in service before its operation becomes satisfactory, and therefore it may happen that a serious nuisance will arise if the sludge is discharged too early upon the drainage beds. Such a condition occurred at two of our plants, Recklinghausen and Bochum, before we had learned by experience how to prevent it; but after they had been in operation a sufficient length of time the development of all disagreeable odors ceased. If it becomes necessary for any reason to discharge undecomposed sludge during this ripening period, the material should be treated like other freshly deposited sludge, such as quick burial in the ground. The large amount of gas contained in Emscher tank sludge, 75 per cent. of which is methane (CH_4), and therefore combustible, and 25 per cent. carbonic acid (CO_2), has already been mentioned in Spillner's earlier paper. These gases also contain traces of hydrogen, nitrogen, ammonia and sulphuretted hydrogen. The part played by these gases in rendering the sludge mobile and in facilitating its drainage and drying has also been explained.

The specific gravity of the sludge obviously varies with the amount of gas present. This is demonstrated by the fact that from time to time large quantities of sludge will detach themselves from the bottom of every septic tank and rise to the surface of the liquid, where they discharge their contents of gas and then sink again to the bottom. Sludge that is free of gas has a specific gravity of 1.09 to 1.22.

Details of analyses are given in the following Tables I, II and III, relating to the Recklinghausen, Essen and Bochum plants.

In regard to the analyses at Recklinghausen, it should be remarked that since the end of 1908 this sludge cannot be considered as normal Emscher tank sludge, because the capacity of the plant has been greatly exceeded by the unexpectedly

rapid increase in the quantity of sewage, and hence the time required for a thorough decomposition of the sludge is no longer available. The quality of the sludge, moreover, is different from what it was formerly. No bad results, however, have yet appeared, as the change in quality is manifested only by the larger water content of the sludge, and the longer time required for its drainage on the beds; but it does not become putrid in drying, which is the main thing to be attained. It is intended to relieve the tanks to some extent by first passing the sewage through a detritus chamber which will extract the sand and other heavy matter. The rapid increase in the quantity of sewage from the other cities will also affect the remaining plants by reducing the time available for the decomposition of the sludge.

Table I gives 30 analyses of liquid sludge from the 6 Emscher tanks of the Recklinghausen plant, taken on 15 different days between June 14, 1907, and September 2, 1910, three or four analyses of the same date often relating to the sludge from different tanks; the depth of the tanks is not stated. The essential figures are as follows:

TABLE I

ANALYSES OF EMSCHER TANK SLUDGE. RECKLINGHAUSEN

	Max.	Min.	Average
Water content, per cent	88.3	75.0	82.9
Dry matter, per cent	25.0	11.7	17.1
Mineral component of dry matter, per cent	64.4	40.8	54.7
Organic component of dry matter, per cent	59.2	35.6	45.3
Nitrogen component of dry matter, per cent	3.64	1.18	1.74
Fat component of dry matter, per cent . .	10.79	5.17	6.87

Table II gives 16 analyses of liquid sludge from the 9 Emscher tanks of the Essen-N. W. plant, taken on 15 different days between April 4 and October 11, 1909; 6 of these analyses refer to either mixtures or averages from 2 or 3 tanks. All these tanks are 9 m. = 29.5 ft. deep. The essential figures are as follows:

TABLE II

ANALYSES OF EMSCHER TANK SLUDGE. ESSEN

	Max.	Min.	Average
Water content, per cent	81.8	71.3	75.6
Dry matter, per cent	28.7	18.2	24.4
Mineral component of dry matter, per cent	53.5	37.6	45.1
Organic component of dry matter, per cent	62.4	46.5	54.9
Nitrogen component of dry matter, per cent	1.43	1.02	1.22
Fat component of dry matter, per cent	7.36	3.44	4.95

Table III gives 24 analyses of liquid sludge from the 18 Emscher tanks of the Bochum plant, taken on 11 different days between February 11, 1909, and December 13, 1910. All of these analyses refer to single tanks; the depth of the tanks is not stated. The essential figures are as follows:

TABLE III

ANALYSES OF EMSCHER TANK SLUDGE. BOCHUM

	Max.	Min.	Average
Water content, per cent	83.9	70.9	78.1
Dry matter, per cent	29.1	16.1	21.9
Mineral component of dry matter, per cent	71.5	49.3	61.9
Organic component of dry matter, per cent	50.7	28.5	38.1
Nitrogen component of dry matter, per cent	1.50	0.87	1.18
Fat component of dry matter, per cent	12.30	3.53	6.12

It has been observed that the water content of the sludge depends in high degree on the depth of its surface (as determined by sounding in the manner described in the foregoing) below the surface of the water in the tank, and also upon the age of the sludge. If a tank contains only a small quantity of sludge, the presumption is that the sludge was deposited quite recently and that it will contain a relatively high percentage of water. This is always the case in our tanks at the end of summer, as they are operated so as to discharge as much sludge as can possibly be dried during the warm season, and thus make room in the tanks for the accumulation of sludge during the frosty days when it cannot be discharged upon the drainage beds. On the other hand, if the septic chambers are filled to a high level as

will be the case in plants of sufficient capacity to hold the sludge accumulations of from 2 to 4 months, the sludge will contain a very low percentage of water. The normal low percentage at the Bochum and Essen plants is about 73 per cent.

The easy separation of the liquid sludge into water and a spadable mass is explained not only by the action of the gases already mentioned, but also by the fact that the organic matter has undergone an extensive decomposition. Unfortunately a measure for this decomposition cannot be deduced from the available analyses, as the data are not sufficiently complete to admit of a comparison with the composition of the fresh sludge; but other investigations are now in progress from which it will be possible to make such a comparison. We can, however, form a rough estimate of the extent of the sludge destruction or digestion by considering the volume of the gases produced. Several measurements of this volume were made at Essen-N. W., and it was found that the plant yielded from 24,700 to 31,800 cu. ft. (700 to 900 cbm.) of gases per day. The weight of such gas is about (1.6855 lbs. per cubic yard, or 0.0624 lbs. per cubic foot) (1 kg. per cbm.), and hence from 1540 to 1980 lbs. (700 to 900 kg.) of organic matter in the sludge were gasified every day. The records show that during that period the average daily production of decomposed liquid sludge was 18.31 cu. yds. (14 cbm.), of which 24 per cent. was dry matter; and as the specific gravity of the sludge is approximately 1.00, the daily yield of dry matter was accordingly 4.39 cu. yds. (3.36 cbm.) or 7407.5 lbs. (3360 kg.), of which about 55 per cent. or 4078.5 lbs. (1850 kg.) is of organic nature. Let us now assume that the loss or destruction of organic matter in the sludge takes place exclusively by gasification, as we do not yet know the proportion thereof that is lost by becoming liquefied; this daily loss will then be represented by the aforesaid weight of 1540 to 1980 lbs. (700 to 900 kg.), or 1763.7 lbs. (800 kg.) on the average, of gas produced every day by the tanks. By adding this loss to the aforesaid residual organic matter in the decomposed liquid sludge, we will have for the daily quantity of organic matter that reaches the tanks: $4078.5 + 1763.7 = 5842.2$ lbs. $(1850 + 800 = 2650$ kg.). From this computation it is seen that about one-third of the organic matter contained in the fresh sludge is lost or destroyed by gasification. [Provided that no liquefaction occurs. It should also be remembered that these figures cannot be checked

by the actual amount of organic matter in the freshly deposited sludge, which was not ascertained. *Trans.*]

The foregoing figures cannot be regarded as being generally correct, as they relate to only one plant and a few measurements of the gas there evolved. They afford, however, some means of estimating how much sludge is lost by gasification in a properly working Emscher tank located in our climate. Reference may also be made to the experiments of Favre and Spillner for determining in another manner the loss of sludge by decomposition in a septic tank, published in *Gesundheitsingenieur*, 1907, p. 810 and 1909, p. 825, respectively.

The septic liquid sludge is a watery mixture of mineral and partly decomposed organic matter. On evaporation, the resulting dry matter has usually a gray color, but sometimes it is brownish-gray. It has little odor, and that which is developed when heated to 212° F. usually resembles the odor of peptone. In most cases it contains few recognizable materials, but when such are found they are commonly bristles, hairs, stems of grains, small twigs, scraps of leather, sand, small stones, and fragments of coal; bits of tinfoil, card-board, wood and lime, and fish-scales have also been found therein repeatedly.

The determination of the total amount of nitrogen in the dry sludge is made regularly, in view of the utilization of this material as a fertilizer at some of the plants. The resulting figures have exceeded our expectations, the averages being 1.22 per cent. at Essen-N. W., 1.39 per cent. at Bochum, and 1.57 per cent. at Rechlinghausen. All of the spadable sludge produced at the latter plant has been sold for fertilizing purposes, and good results have been attained therewith.

Many determinations of the amount of fat in the dry sludge were made, but it was found that it was considerably less than that of the fresh sludge in other cities. Thus from 16 to 17 per cent. of fat was obtained from the dry matter of the fresh sludge at Frankfort, 18 per cent. at Lüttich, 15 per cent. at Cassel and 14 per cent. at Harburg, while the amount obtained from the dried sludge of the typical Emscher tanks at Essen-N. W. and Bochum was only from 3 to 7 per cent. in most cases. The difference must be ascribed to the decomposition attained in the latter plants. Inasmuch as the recovery of this fat has never proved profitable in other localities, it seems hopeless to attempt such a process where Emscher tanks are used.

Excepting the small proportion that is used as fertilizer, the bulk of the drained sludge produced by the plants of the Emscher Assocation is used at the present time for filling depressions and low places.

In regard to the mineral matter of the dry sludge, a number of determinations of its principal components were made. The averages found at Essen-N. W. are: SiO_2, 63.29 per cent.; Fe_2O_3, 11.37 per cent.; Al_2O_3, 6.56 per cent. It thus appears that the mineral matter in the sludge consists chiefly of sand.

Examinations of the Drained Sludge

The sludge is described as "spadable" when it can be cut and handled with shovels on the drainage beds like moist earth, and be loaded into the tram-cars provided for its transportation to other localities. For the purpose of examination a number of samples, depending on the size of the drainage bed, are collected from different points and are then mixed together; the mixture is regarded as representing an average sample of the material, and is then placed in an air-tight receptacle and taken to the laboratory. The examination is made in the same manner as in the case of the liquid sludge.

The surface of the spadable sludge has usually a grayish-brown color, while the remainder of the mass is mostly black. Its consistence varies from doughy to crumbly, according to the amount of moisture present, which in turn depends on the state of the weather and the length of time allowed for drainage. In structure, the spadable sludge from Emscher tanks is invariably somewhat spongy. On breaking an air-dried sample, the ruptured surfaces exhibit numerous small cavities and passages penetrating the entire mass, which were formed by the bubbles of gas contained in the liquid sludge, and obviously facilitate both drainage and subsequent drying in high degree.

As the collection of a fairly representative sample of a large mass of partly dry sludge is a matter of considerable difficulty, the examinations of spadable sludge have not been as numerous as those of the liquid sludge. Table IV gives the results of 13 examinations of spadable sludge at the Essen-N. W. plant, on 11 different days between April 19 and August 28, 1909; and with periods of drainage ranging from 11 to 3 days. The essential figures are as follows:

TABLE IV

ANALYSES OF SPADABLE EMSCHER TANK SLUDGE. ESSEN-N. W.

	Max.	Min.	Average
Water content, per cent	59.9	47.7	52.3
Dry matter, per cent	52.3	40.1	47.7
Mineral component of dry matter, per cent	54.2	40.6	46.6
Organic component of dry matter, per cent	59.4	45.8	53.4
Nitrogen component of dry matter, per cent	1.40	1.01	1.17
Fat component of dry matter, per cent	3.91	3.02	3.39
Drainage period, number of days	11	3	7

The results of 5 examinations of both the liquid sludge and the resulting spadable sludge at the Essen-N. W. plant, on the same number of days between May 25 and August 7, 1909, is given in Table X of Spillner's paper, pages 167 and 168.

The averages of the results found from the examinations (number not stated) of spadable sludge at the Bochum plant during the fiscal year 1910–1911 are:

Water content, 63.3 per cent.; dry matter, 36.7 per cent.; mineral component of dry matter, 64.4 per cent.; organic component of dry matter, 35.6 per cent.; nitrogen, 1.24 per cent.; fat, 6.91 per cent.

Table V gives the results of 21 examinations of spadable sludge at the Recklinghausen plant, made on 9 different days between May 27, 1908, and October 10, 1910. Two of these were made in 1908 and the remainder in 1910. The essential figures are as follows:

TABLE V

ANALYSES OF SPADABLE EMSCHER TANK SLUDGE. RECKLINGHAUSEN

	Max.	Min.	Average
Water content, per cent	73.6	53.5	65.2
Dry matter, per cent	46.5	26.4	34.8
Mineral component of dry matter, per cent	65.4	41.2	58.5
Organic component of dry matter, per cent	58.8	29.8	41.5
Nitrogen component of dry matter, per cent	2.39	0.95	1.65
Fat component of dry matter, per cent	10.30	3.02	5.28
Drainage period, number of days	22	4	12.5

It should be noted that the high average water content (65.2 per cent.) of the spadable sludge at Recklinghausen, together

with the long average drainage period (12.5 days), is attributable to the overworking of the plant and the consequent lack of thorough decomposition of the sludge.

The examination of the dry matter of the drained sludge is made in the same manner as in the case of the liquid sludge. The amount of organic matter is generally somewhat less than that in the liquid sludge, but it may be remarked that in view of the large quantities of material examined, it is very difficult to obtain concordant samples. Experiments on a small scale, however, have shown that some organic matter disappears by gasification during the process of draining. A description of these latter experiments is given in Spillner's earlier paper, pages 161–164. Some instances of such loss in drying are also found in Table X of Spillner's paper relating to the sludge of the Essen-N. W. plant.

This table likewise shows that the reduction in the amount of dry matter contained in the liquid sludge, caused by drainage on the sludge beds, ranges from 0.15 to 0.95 per cent. After the spadable sludge has been removed to the final dumping grounds, the process of decomposition continues, although slowly. No analyses have yet been made in regard to this matter, but from the high temperatures (up to 122° F.) that have occasionally been observed in such deposits, it must be concluded that further processes of decomposition are taking place therein.

Examination of the Liquid Drawn From the Septic Chamber of an Emscher Tank, and the Drainage Water From the Sludge Beds

A knowledge of the composition of the liquid in the septic chamber of an Emscher tank is of interest to those who operate such plants, because this liquid is contained in the sludge that is discharged from the tank, and is separated therefrom in part when the sludge reaches the drainage beds, and thence finds its way into the outfall. When a tank is first put in service, the septic chamber is filled with the sewage; but as there is no current in this chamber, the original volume of sewage soon becomes septic and undergoes thorough decomposition, after which it has little odor. A renewal of the liquid by diffusion from the sewage that flows through the upper chamber of the tank, or by the water that is mixed with the sludge which drops

into the septic chamber through the slot in the bottom of the upper chamber, is usually a very slow process; but when some of the accumulated sludge is discharged, its volume is necessarily replaced with fresh sewage from the upper chamber.

The quantity of sludge discharged at one time, however, is always a very small fraction of the capacity of the septic chamber, and the liquid therein is then allowed to remain at rest for several weeks as a rule. During this time the fresh sewage that replaced the volume of previously discharged sludge is afforded ample time to become thoroughly decomposed. This process of decomposition is also accelerated by the constant rise of gas bubbles from the sludge below, whereby the liquid contents of the septic chamber becomes thoroughly intermixed.

If a sample of the liquid in the septic chamber is taken midway between the floating scum at the top of the ventilating openings and the surface of the dense sludge at the bottom, it will be found to be black in color; and on being allowed to stand, the upper portion will gradually become clear while the lower portion will contain much sludge. In the tank a part of this sludge was being carried up by the ascending gas bubbles, and another part was in the act of settling again to the bottom. The averages of the results of a large number of analyses of such liquid is given in the following Table No. VI:

TABLE VI

ANALYSES OF LIQUID FROM SLUDGE CHAMBER OF EMSCHER TANKS

Name of plant	Recklinghausen	Bochum	Essen-N. W.
Number of analyses made	17	6	15
Transparency of the liquid	0.80	1.97	0.34
Reaction of the liquid	Alkal.	Alkal.	Alkal.
Chlorine, parts per million	183.0	993.3	2193.9
Residue after evaporation, parts per million	990.7	2594.1	4662.2
Residue after ignition, parts per million	693.7	2379.8	3961.9
Loss by ignition, parts per million	297.0	214.3	700.3
Suspended matters, parts per million	2171.9	81.8	5670.2
Suspended organic matter, parts per million	1044.3	18.7	3969.9
Suspended mineral matter, parts per million	1125.6	63.1	1700.3
Nitrates, parts per million	0	0	0
Nitrites, parts per million	0	0	0
Total nitrogen, parts per million	36.3	25.4	70.4
Nitrogen as ammonia (NH_3), parts per million	27.8	20.5	61.4
Nitrogen as organic nitrogen, parts per million	8.5	4.9	9.0
Sulphuretted hydrogen	Present.	Present.	Present.

On comparing these figures with the corresponding analyses of the sewage in the upper chambers of the Emscher tanks at the three plants mentioned, it will be seen that the septic liquid contains considerably more dissolved matter than the sewage.

As already stated, this septic liquid is mixed with the sludge that is discharged upon the drainage beds. These beds are formed of a layer of slag or cinders about 12 in. deep, over which another layer of fine-grained material is placed. This upper layer absorbs the water that drains out very slowly from the sludge, and gradually delivers it to the underlying stratum of cinders from which it escapes into the drain pipes. Both the upper stratum and the lower one absorb much of the organic matters in the liquid, and these matters are then transformed or mineralzed by the micro-organisms in the interstices, in the same way as in a contact bed or sprinkling filter. This mineralized matter is then flushed out by the following water, and flows therewith into the underdrains. The water issuing from the drain pipes is thus biologically purified, and its character can be estimated from the averages of the results of 12 analyses of samples of the water taken from the under-drains of the sludge beds of the Essen plant, given in Table VII, as follows:

TABLE VII

ANALYSES OF WATER FROM UNDERDRAIN OF SLUDGE BEDS, ESSEN

Determinations	Parts per million	Determinations	Parts per million
Transparency	6.65	Nitrous acid (N_2O_3)	Present
Residue after evaporation	2674.9	Nitric acid (N_2O_5)	Present
Residue after ignition	2311.4	Total nitrogen	52.3
Loss by ignition	363.5	Nitrogen as ammonia	28.9
Chlorine	529.2	Organic nitrogen	2.1
Suspended matters	124.4	Total nitrogen in nitrites and nitrates	21.3
Suspended organic matter	48.8	Putrescibility	Not putres.
Suspended mineral matter	75.6		

These analyses relate in part to waters derived from other Emscher tanks than those which furnished the samples of septic liquid cited in Table VI, and hence a direct comparison between the two results of analysis cannot be made. The figures, however, indicate plainly that a biological purification has taken place, as shown by the presence of nitrates and nitrites and also

by the small quantity of organic nitrogen. This drain water can fairly be regarded as suitable for admission into almost any outfall, and even into such as are sensitive to pollution. It accordingly requires no further treatment, and differs in this respect greatly from the drainage waters of filter presses and centrifugal sludge driers. Its quantity, moreover, is very small, being only one gallon to every 10,000 gallons of sewage at Essen N. W., so that it may be allowed to soak away into the ground at plants of moderate size.

Yearly Costs

The total annual expenses of a sewage clarification plant consist of the interest and sinking fund charges on the cost of the land and structures, the charges for maintenance and renewals, and the usual outlays for supervision, labor and supplies. The figures for the Recklinghausen, Bochum and Essen N. W. plants, along with some other details, are exhibited in the following Table VIII:

TABLE VIII

Cost of Operation and Maintenance

Name of plant	Tributary population	Dry weather flow of sewage mill. gals. per day	Total annual expenses	Total annual cost per head of population	Total annual cost per million gals.	Annual expense for operation and maintenance	Annual expense for operation and maintenance per head
Recklinghausen	30,000	2.38	$2,355	$0.0785	$2.71	$ 750	$0.0250
Bochum	145,000	13.22	10,188	0.0703	2.11	3600	0.0248
Essen N. W.	60,000	12.69	6,155	0.1026	1.33	2200	0.0367

[It should be noted that in all of these three plants neither the sewage nor the sludge is pumped, and that no chemicals are used to induce precipitation of sludge or disinfection of the effluents; also that the effluent from the settling chambers, which form the upper portions of the Emscher tanks, is not subjected to any further treatment whatever, but flows directly into the outfall. No figures are given as to costs of land and constructions; nor are the stated annual costs applicable to American municipalities where materials, wages and labor are much higher than in Germany.—*Trans.*]

GENERAL RESULTS

If all connections between the sewers and privy-vaults or cesspools are abolished, the water-carried sewage will reach the disposal plant in a fresh condition. The temperature of the sewage in winter is high enough to prevent its freezing in the plant. [The lowest temperature of the air at these plants during the 14 months from January 1, 1909, to March 1, 1910, was about 14° F., and prevailed for only two or three consecutive days; the temperature diagrams given in the paper show that the temperature of the air was below the freezing-point (32° F.) on from 12 to 30 days in the aggregate during this period.—*Trans.*]

If the sewage is not septic when it reaches the plant, it will not become septic during its passage through the upper settling chambers of the Emscher tanks. [The cylindrical tanks are combined into groups of three at the plants mentioned, thus making the length of each continuous settling chamber about 100 ft., and the time allowed for the sewage to traverse this distance ranges from 30 to 56 minutes on the average in dry weather. When the volume of sewage is increased by rainfall, the time of passage is reduced.—*Trans.*]

Tests for putrescibility of mixtures of the effluent with the unpolluted water of the several small streams into which the clarified sewage is discharged, show that offensive odors are not developed in a mixture of equal parts of effluent and clean water, and sometimes not in a mixture of two parts of effluent to one of clean water, even when kept standing in an incubator. The putrefaction of the stream is therefore not to be apprehended.

If the time of flow through the aforesaid settling chamber is not less than 45 minutes, about 95 per cent. on the average of the entire volume of sedimentable matter in the sewage will be deposited in the septic chambers underneath. The effluent will accordingly contain not more than one volume of sedimentable matter in 2000 equal volumes of the liquid. [The term "sedimentable matter" applies to the sludge or sediment which settles in the course of 2 hours into the lower part of a receptacle filled with crude sewage and left undisturbed.—*Trans.*]

Coal dust requires a much longer time for settlement than the sludge of domestic sewage; in experiments with fine coal dust it was found that from 4 to 8 hours were necessary for its

sedimentation. It is therefore important to exclude from the sewers all waters that have been used for washing coal and coke and have not undergone long sedimentation.

When the volume of sewage is largely increased by storm water, no appreciable quantity of sludge can be flushed out from an Emscher tank, because the sludge does not accumulate in the settling chamber through which the sewage flows, but drops at once into the septic chamber below where it remains undisturbed by the current in the upper chamber.

The volume of the fresh sludge deposited in an Emscher tank is reduced about 85 per cent. by the process of decomposition in the septic chamber. From 25 to 30 per cent. of the dry matter contained in the fresh sludge will be destroyed by gasification. The gases thus produced consist mostly of methane (CH_4) and carbonic acid (CO_2). Offensive odors are not developed in the process of gasification. The rest of the reduction in the volume of the sludge is principally due to the diminution of its content of water. The proportion lost by liquefaction is as yet unknown.

The drying or draining of the sludge to a spadable consistency upon suitable beds is accomplished in 6 days on the average. A depth of from 8 to 10 in. of liquid sludge is deposited on the beds each time they are used. In the course of the drying process the volume of the sludge is reduced about 25 per cent. During a year an aggregate depth of 20 ft. of liquid sludge is applied to each bed. After the spadable sludge reaches the dumping ground, it is gradually transformed into an earthy substance. The drainage water from the sludge beds is biologically purified in passing through them.

The cost of clarifying sewage with Emscher tanks is small, as seen from the preceding table.

SLUDGE TREATMENT IN THE UNITED STATES

BY

KENNETH ALLEN, M. AM. SOC. C. E.

SLUDGE TREATMENT IN THE UNITED STATES

I. American Sewage

In applying data of sewage purification the character of the sewage itself is of first importance: in particular, its composition and age. It should be borne in mind that results obtained under European conditions, where a water consumption of about 40 gallons per capita daily is a usual amount, may be quite different under American conditions, where a water consumption of 100 or even 125 gallons per capita daily is not uncommon. So, too, a distinction is necessary between sewages from combined and separate systems, the former being greatly diluted and increased in volume during rainy weather, besides bringing with it much grit from the street surfaces. Trade wastes, when produced in excessive amounts, often constitute a special problem, either when taken in combination with the ordinary sewage or when treated independently; but ordinarily their influence is not sufficient to determine the method of purification to be adopted.

The amount of the impurities to be dealt with in the case of dry-weather or domestic sewage depends on the population served rather than on the volume of liquid, so that in questions relating to sludge treatment populations are generally preferable as a basis of computation rather than volumes of liquid.

Table I gives the analyses of the sewage of several American cities, and Table II gives the amount of the suspended solids and the part of this which is organic or liable to cause offensive conditions through putrefaction—figures of first importance in question of sewage clarification and sludge treatment.

TABLE I

ANALYSES OF THE SEWAGE OF SEVERAL AMERICAN CITIES. PARTS PER MILLION

City		Boston[1]	Worcester	Columbus	Philadelphia	Lawrence	Waterbury	Chicago
Year		1904–1905	1909–1910	1904–1905	1909–1910	1908	1908	1909
System		Combined	Partly separate	Partly separate	Separate	Combined	Combined	Combined
Organic Nitrogen.[2]	Total			9.0	6.3		14.8	7.3
	Dissolved			3.3			10.3	
	Suspended			5.7			4.5	
Ammonia: Free		17.6	22.82	11.0	4.0	41.7		8.5
Albuminoid.	Total	5.67	7.04			6.6		
	Dissolved	2.96	3.26			3.4		
	Suspended	2.71	3.78			3.2		
Oxygen Consumed	Total	41.5	109.8	51	76	55.7	46	35.8
	Dissolved	24.6	64.6	26	40.4		26	
	Suspended	16.9	45.2	25	15.6 (Settling)		20	
	Colloidal				20.0			
Chlorine			96.1	65	39	143.0	48.0	36.5
Residue on Evaporation	Total		789	996		732[3]		
	Dissolved		545	787		524[3]		
	Suspended		244	209	189	208[3]	165	143
Volatile.	Total		367	185		342[3]		
	Dissolved		228	106		183[3]		
	Suspended		139	79	130	159[3]	115	80
Fixed:	Total		422	811		390[3]		
	Dissolved		317	681		341[3]		
	Suspended		105	130	59	49[3]	50	63
Iron			48.3					
Sulphur			46.9					
Fats				25	28		26	
		Contrib. San. Res. Lab. III. Table I.	An. Report. Supt. of Sewers Table VII	Rep. Sew. Purif., 1905, p. 26.	Rep. on Disp. of Sew., 1911, p. 33.	Rep. Mass. S. B. H. 1908, p.p 265, 267	*Eng. News*, June 3, 1909.	*Mun. Jour.*, Oct. 4, 1911.

[1] After passing coarse screen and grit chamber.

[2] George W. Fuller gives the following relation between organic nitrogen (N) and nitrogen as albuminoid ammonia (A) as appoximately true for most Massachusetts sewages: $N = 12 A^2 +$ nitrogen as free ammonia. *Tech. Quarterly*, June, 1903. [3] 1902.

TABLE II

SUSPENDED MATTER IN THE SEWAGE OF SEVERAL AMERICAN CITIES

a. Parts per Million

Place	Total	Organic	Mineral	Authority
Boston, Mass.	135	91	44	Kinnicutt, Winslow & Pratt.
Chicago, Ill.	143	80	63	*Eng: News*, Mar. 31, 1910.
Columbus, O.	215	81	134	Geo. A. Johnson.
Lawrence, Mass.	149	113	36	Kinnicutt, Winslow & Pratt.
Mass.—Small towns	94.6	78.1	16.5	Kinnicutt, Winslow & Pratt.
Small cities	180.6	46.4	31.2	Kinnicutt, Winslow & Pratt.
Paterson, N. J.	45 to 641			George C. Whipple.
Philadelphia, Pa.	204	142	62	Geo. S. Webster.
Plainfield, N. J.	134			Andrew Gavet.
Providence, R. I.	397	343.5	53.5	Kinnicutt, Winslow & Pratt.
Waterbury, Conn.	165	115	50	*Eng. News*, June 3, 1909.
Worcester, Mass.	255.8	177.8	78.0	Kinnicutt, Winslow & Pratt.
	b. Grams per Capita.			
Chicago, Ill.	166	93	73	*Eng. News*, Mar 31, 1910.
Columbus, O.	98	47	51	Geo. A. Johnson.
Mass.—Small cities	53	44	9	Kinnicutt, Winslow & Pratt.
Mass.—Separate systems.	49	38	11	Geo. A. Johnson.
Mass.—Combined and mfg.	145	76	69	Geo. A. Johnson.
United States	93	40	53	Geo. W. Fuller.

Although the composition of sewage varies greatly in different cities the following analyses may be taken as fairly representing ordinary American conditions.

TABLE III

COMPOSITION OF TYPICAL AMERICAN SEWAGE

In Grams per Capita Daily[1]

1. According to George C. Whipple[2]

	Domestic sewage	Sewage of manufacturing cities
Total solids	170	220 to 500
Organic matter	70	100 to 200
Mineral matter	100	120 to 300
Chlorine	20	25 to 50
Nitrogen	11	13 to 15
Albuminoid ammonia	1 7	2 to 4
Free ammonia	7	5 to 10
Fats	20	20 to 50

2. According to George W. Fuller[3]

Oxygen consumed	2 minutes' boiling	15.0
	5 minutes' boiling	22.0
Nitrogen as	Free ammonia	7.0
	Albuminoid ammonia	2.5
	Organic	8.0
	Total	15.0
Chlorine		19.0
Fats		19.0
Dissolved matter	Mineral	99.0
	Organic and volatile	37.0
	Total	136.0
Suspended matter	Mineral	53.0
	Organic and volatile	40.0
	Total	93.0
Total solids	Mineral	152.0
	Organic and volatile	77.0
	Total	229.0

[1] To convert to ounces per capita multiply by 0 0327.
To convert to grains per capita multiply by 15.432.
If the volume of sewage is taken as 100 gallons per capita daily:
To convert to grains per gallon multiply by 0 1543.
To convert to parts per million multiply by 2 6417.

[2] Report on Sewage Disposal, Paterson, N. J., 1906.

[3] *Technology Quaterly*, June, 1903, p. 141.

3. According to E. B. Phelps [1]

	In solution	In suspension	Total
Mineral and ash	114	38	152
Organic and volatile	76	76	152
Total residue on evaporation	190	114	304

The organic matter is composed as follows:

Total carbon	76.0
Total nitrogen	5.7
Total H, O, S, P, etc	70.3
	152.0

Separating the nitrogenous from the carbonaceous matter there results:

Nitrogenous matter:		
Nitrogen	5.7	
Carbon	28.5	
H, O, S, P, etc	22.8	
		57.0
Fats, etc.:		
Carbon	13.3	
H and O	5.7	
		19.0
Carbohydrates:		
Carbon	34.2	
H, O, etc	41.8	
		76.0
Total		152.0

II. Detritus form Grit Chambers

Boston, Mass.—At the sewage experiment station of the Massachusetts Institute of Technology, the sewage was pumped by a small duplex pump from a large sewer carrying the combined sewage of 350,000 persons. A small grit chamber was formed of

[1] Deduced from Water Supply and Irrigation Paper, No. 185. Table, p. 15, Assuming 100 Gals. Per Cap.

a cast iron cylinder 19 in. in diameter and 16 in. deep, containing a screen with 1/2-in. meshes. The velocity was reduced in this to 0.04 ft. per second, thus making the time of passage through the chamber about 45 seconds.

The detritus removed from this chamber amounted to 0.65 cu. yds. per million gallons of sewage. It contained 27 per cent. moisture and but 6.65 per cent. organic matter, and were quite inoffensive when spread on the land adjoining the station.[1] Analyses of samples taken from March 26, 1904, to June 1, 1905, averaged as follows:[2]

	Wet detritus	Water	Clean stone, etc.	Fine dry detritus			
				Total	Loss on ignition	Organic N	Oxygen consumed
Pounds per million gallons sewage.	1600	430	190	970	106	2.2	1.7
Parts per million parts of sewage.	190	52	23	117	13	.26	.2

Near the Moon Island outlet of the Boston Main Drainage system the outfall sewer is enlarged to form two conduits 8 ft. wide, 16 ft. high and about 1/4 mile in length, in which the heavier solids deposit. The depth of sewage in these sewers of deposit is designed to be from 8 to 10 ft. The sludge is pushed toward one end where it is drawn off by a 12-in. pipe to a sludge tank 50 ft. × 10 ft. × 15 ft. in size, having a capacity of 150 cu. yds. From this tank it is taken by a scow, which is towed about 20 miles to sea, and dumped.

In the year ending February 1, 1910, with an average flow of 82,378,000 gallons per day, 8773 cu. yds. of sludge was deposited in these sewers, or 0.29 cu. yds. per million gallons of sewage, in addition to whatever was subsequently deposited in the storage tanks on Moon Island.

Worcester, Mass.—The sewage, which, in 1910, averaged 14.57 million gallons per day, or 107.2 gallons per capita, passed through one of two grit chambers 40 ft. × 10 ft. in plan and 9 ft. deep in about 1.8 minutes. The mean velocity was, therefore, 0.4 ft. per second.

[1] Experiments on the Purification of Boston Sewage, Winslow and Phelps. Water Supply and Irrigation Paper No. 185.

[2] Kinnicutt, Winslow and Pratt.

According to Mr. Matthew Gault, superintendent of sewers, 565 cu. yds. of heavy grit, about half water and weighing 18,150 lbs. per cubic yard, were removed, representing 4.0 per cent. of the total suspended matter in the sewage. The effluent contained 276 parts per million of suspended matter. The material removed amounted to 0.11 cu. yds. per million gallons of sewage. The cost of removal from the grit chambers and placing it in carts (shoveling 3 times) was 33 1/3 cts. per cubic yard, and the cost of hauling about 600 ft. and dumping, 50 cts. per cubic yard, making the total cost of disposal 83 1/3 cts. per cubic yard or 9 1/4 cts. per million gallons of sewage.

Columbus, Ohio.—The first grit chamber used at the experimental station was 40 ft.×8 ft.×7 1/2 ft. deep. This was subsequently changed to 39.5 ft.×5 ft.×2.5 ft. in depth, with a bottom baffle a foot high, 2 ft. from the inlet and a surface baffle extending to about 6 in. from the bottom, 3 ft. from the inlet.

In the former the average velocity was 0.518 ft. per minute (2.61 mm. per second) and the period of flow 1.3 hours; in the latter the average velocity was 2.28 ft. per minute (11.39 mm. per second) and the period of flow 0.29 hour.

The results obtained in the two chambers were as follows:

TABLE IV

		Original grit chamber	Remodelled grit chamber
Per cent. suspended matter in applied sewage which was removed in grit chamber	Total	34	22
	Volatile	30	18
	Mineral	35	24
Cubic yards wet sludge per million gallons		2.55	1.76
Per cent. moisture in sludge, average		87	83
Per cent volatile matter in dry solids		52	46

COMPOSITION OF GRIT CHAMBER SLUDGE

Weight, per cubic yard	1825 lbs..
Specific gravity	1.081.
Water	82.4 per cent.
Soilds	17.6 per cent.
Volatile matter	7.9 per cent.
Nitrogen	0.22 per cent.
Fats	1.22 per-cent

It is difficult to reach a comparison of the above results of rapid sedimentation in grit chambers. The quantity and quality of the material removed depends upon various conditions, such

as the admission of storm water, the character of street surfaces, the use and efficiency of catch basins for the interception of grit, the velocity, depth and time of passage through the grit chamber and the per cent. of moisture in the detritus. With strictly separate systems and domestic sewage the amount would be so small as to be an insignificant factor in questions of disposal, while in combined systems, where the volume may approximate a cubic yard per million gallons of sewage, the amount of putrescible matter is usually so small that the detritus may often be used for filling in land.

Mr. Emil Kuichling[1] mentions the results obtained in various foreign cities, at the Boston experiment station of the Massachusetts Institute of Technology and at the Dorchester pumping station in that city [0.31 cu. yds. per million gallons] and obtains an average of 0.4 cu. yds. per million gallons with a specific gravity varying from 1.52 to 1.87 and a water content of 27 per cent. Under these assumptions the dried suspended matter removed by grit chambers is about 835 lbs. per million gallons, or 100 parts by weight per million.

Waterbury, Conn.[2]—The water supply at Waterbury is 139 gallons per capita, and the sewers are on the combined system. The grit chamber was cleaned frequently so that no gases were formed in the detritus.

Data

Cu. yds. removed per million gallons of sewage	1.40	
Tons removed per million gallons of sewage	1.12	
Specific gravity	1.05	
Moisture	88.3	per cent.
Solids	11.7	per cent.
Mineral matter	5.9	per cent.
Fats	0.78	per cent.
Nitrogen	0.22	per cent.

III. Screenings

A sharp distinction should be made between coarse bar screens intended primarily to intercept sticks of wood, orange and lemon peels, rags, etc., and the fine screens having clear openings of 3/8 in. or less, which have been introduced in increasing numbers,

[1] Notes on Sewage Disposal, Rochester, 1910.
[2] *Eng. News*, Vol. LXI, p. 596.

especially in Germany, to remove as much of the matter in suspension, including fecal matter, as practicable.

The former type is customary in all systems where the sewage has to be pumped, but it has not usually been considered worth

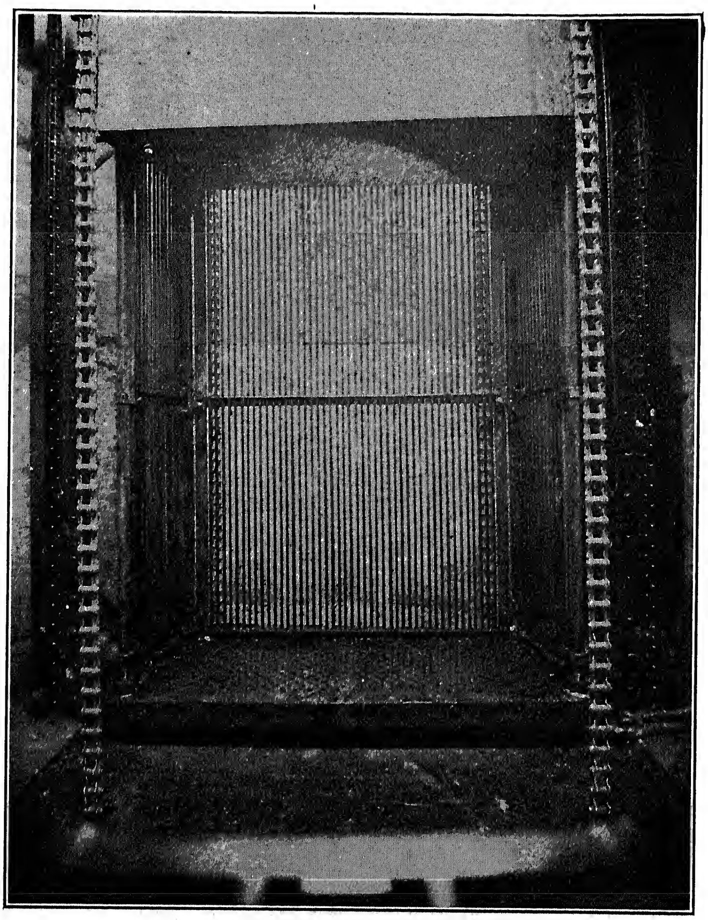

FIG. 37.—Bar screen, Dorchester Pumping Station, Boston.
(Courtesy of F. L. Sanborn, Executive Engineer, Boston Main Drainage.)

while to measure the detritus removed. The following figures are, however, available.

Boston, Dorchester Pumping Station.—Here the combined sewage, amounting in 1909 to 96,373,000 gallons per day, passes through screen cages 7 ft.×3 ft.×7 ft. high, having 3/4 in.

vertical bars on 3 sides spaced 1 in. apart and a floor upon which the screenings fall on raising the cage, and from which they are removed by hand and pressed to remove the excess moisture.

In the year ending February 1, 1910, 573 1/4 tons of wet filth were removed, or 38.1 lbs. per million gallons. The cost of labor at the screens was 0.313 cts. per million gallons.

Boston Metropolitan System.—The screens at the several pumping stations of the Metropolitan Sewerage System are in type similar to those at the Dorchester Pumping Station of the Main Drainage works. The screens are composed of 3/4-in. round bars, 1 1/2 in. center to center and a similar series staggered in front of these, providing an effective, clear space of about 1/8 in.[1]

The following table gives the amount of wet screenings removed from the North and South Metropolitan Systems from the beginning of operation, amounting to 0.10 and 0.16 cu. yds. per million gallons, respectively, during the year 1910, or 5 and 10 cu. yds. annually per thousand population. The sewage is partly separate and partly combined in each system.

The material removed from the screens at the Charlestown and East Boston Pumping Stations June 10, 1898, had the following composition:[2]

Paper	55 per cent.
Rags	25 per cent.
Hair	5 per cent.
Fecal matter and grease	5 per cent.
Refuse from slaughter houses	4 per cent.
Conglomerate matter	6 per cent.
	100 per cent.

Columbus Experimental Plant.—Two vertical removable screens were used, consisting of a diamond mesh of No. 12 wire, the first having 1/2-in. and the second 3/8-in. openings. These removed 36 of the 215 parts per million of suspended matter contained in the sewage, or 0.17 cu. yds. weighing 300 lbs. per million gallons. The weight per cubic yard was therefore about 1765 lbs.

This amount would undoubtedly have been considerably greater, but for the fact that the sewage treated was not drawn from the invert of the trunk sewer and so did not contain all the grit and coarse heavy matter moving along the bottom.

[1] W. M. Brown, chief engineer.

[2] Metropolitan Sewage Com'rs, 1899, p. 25.

TABLE V

MATERIAL REMOVED BY SCREENS OF THE NORTH AND SOUTH METROPOLITAN SEWERAGE SYSTEMS OF BOSTON

	North Metropolitan System									
	Oct., 1900 to Jan., 1902	1902	1903	1904	1905	1906	1907	1908	1909	1910
Population served	324,333	342,321	369,797	387,327	376,575	386,343	422,065	424,050	445,637	465,302
Av. sewage daily. Million gallons	52.0	51.5	53.8	57.2	54.4	58.1	64.3	59.8	60.6	59.0
Av. sew. per cap. daily. Gallons	160	150	145	148	144	150	152	141	136	127
Screenings per million gallons. Cu. yds	.063	.082	.092	.100	.100	.104	.104	.104	.107	.100
Screening per annum per 1000 pop. in cu. yds	3.69	4.50	7.67	5.38	5.34	5.54	5.48	5.43	5.38	5.01

	South Metropolitan System					
	1905	1906	1907	1908	1909	1910
Population served	156,360	167,070	188,150	201,595	233,025	230,365
Av. sewage daily. Million gallons	25.0	33.6	40.6	37.8	40.4	39.6
Av. sewage per cap. daily. Gallons	160	201	216	188	173	172
Screenings per million gallons. Cu. yds	.218	.241	.185	.159	.159	.159
Screenings per annum per 1000 pop. in cu. yds	12.7	17.6	14.5	11.0	10.0	10.04

Note: The volumes are for wet screenings. These weigh about 61 lbs. per cu. ft. After being pressed for final disposal the weight is about 63 lbs. per cu. ft. It is then either burned under the boilers or mixed with ashes at the public dumps.

The liquid, moreover, had previously passed through a 1/2-in. screen and was then pumped, by which much coarse material was removed and fecal matter broken up.

Philadelphia Experimental Plant.—This was supplied with separate system sewage from a 4 ft. 7 in. intercepting sewer through an 8-in. pipe, which entered the sewer 15 in. above the invert. The sewage was then pumped through 413 ft. of 4-in pipe to a point near the testing station, from which it was drawn by gravity. Some of the heavy solids were probably excluded at the start, and the soft fecal matter must have been disintegrated by pumping, as at Columbus.

The sewage was delivered through 24 1/4-in. nozzles upon the conical surface of a screen having 32 meshes per inch (clear openings 0.5 mm. square).

The amount of suspended matter varied considerably, owing to the admission of trade wastes, but averaged from September, 1909, to April, 1910, inclusive, about 200 parts per million, 7/10 of which was volatile. Of this, 63 parts per million, or 33.5 per cent., were removed by the fine screen, equivalent to 560 lbs. of dry solids per million gallons of sewage.

The effect of screening on subsequent treatment was found to be:

1. A more uniform sewage by eliminating in part the irregularities due to trade wastes.
2. A reduction in the sludge subsequently treated.
3. An increase of moisture in the sludge subsequently treated.
4. A finer subsequent sludge and one more readily pumped.
5. An entire absence during 9 months of clogging in sprinkler nozzles using settled screened sewage.

Reading, Pa.—The only important example as yet of fine screening on a working scale in the United States is that at Reading, Pa., with an apparatus devised by Mr. O. M. Weand. This consists of a horizontal cylindrical framework 6 ft. in diam. ×12 ft. long, which is supported on rollers and is rotated by means of a circumferential gear at a rate of 8 revolutions per minute. The cylindrical framework is covered with wire cloth of monel metal having from 30 to 36 meshes to the linear inch, which is, in turn, supported by a screen of No. 12 copper wire with 5/8-in. meshes.

The sewage enters at one end and is distributed by flowing over a weir placed in the first half of the cylinder parallel to the axis.

It then flows through the bottom of the screen and is conveyed away, leaving the sludge and other coarse material inside.

By the rotation of the screen the sludge is worked forward by a narrow spiral plate, which projects from the inner surface until it reaches the further end, where it is lifted by a series of short radial buckets attached to the perimeter. On reaching a

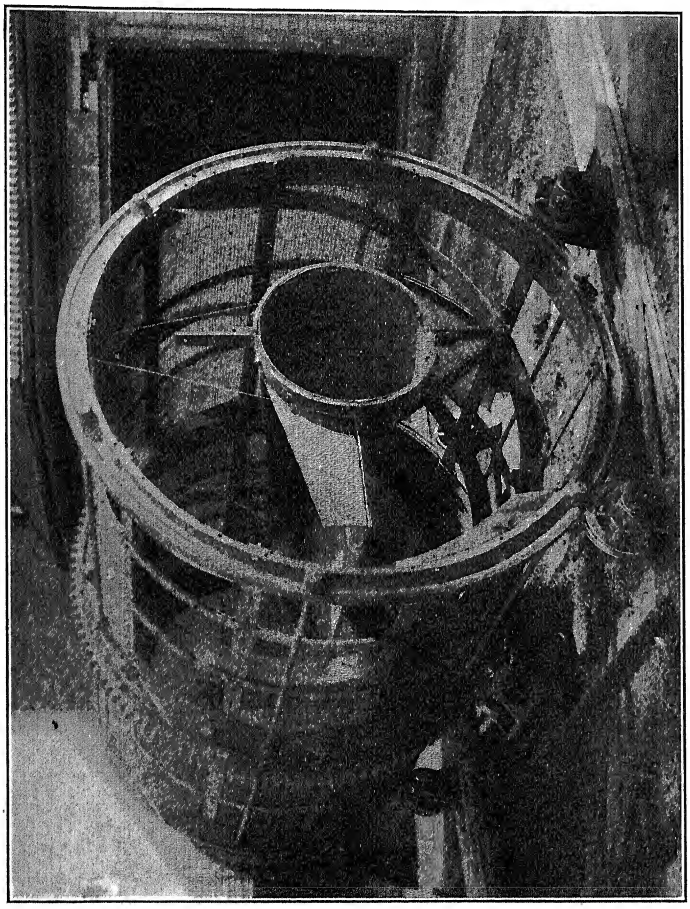

FIG. 38.—Fine mesh screen, Reading, Pa. (Courtesy of O. M. Weand.)

certain elevation the sludge slips off upon a sloping trough, which delivers it through the end of the cylinder and drops it into a receptacle from which it is raised and transported by suitable conveying machinery to an elevated sludge tank.

The sludge that collects on the screen is washed off by 12 1/16-in. water jets in each of two horizontal pipes placed just outside

the screen—one on each side. Each pipe is moved back and forth longitudinally by a toggle joint at one end so that the entire surface of the screen can be freed of detritus. Screened sewage has been used in place of water for this purpose satisfactorily, but the jets clog rapidly with the unscreened liquid. Hair, lint and other fibers are not so readily removed, however, and this difficulty, inherent in any fine wire mesh, would probably cause trouble in its use with some classes of sewage.

According to Mr. C. B. Ulrich, City Engineer of Reading, the volume of sewage handled is about 5 million gallons daily from 40,000 persons. It contains 125 or 130 parts per million of suspended solids. The screenings amount to 1.15 cu. yds. per million gallons, and have the following general composition:

	Wet	After Centrifuging
Moisture	89.5 per cent.	73.0 per cent.
Mineral matter	2.8 per cent.	7.4 per cent.
Volatile matter	7.7 per cent.	19.6 per cent.
	100.0 per cent.	100.0 per cent.

The weight of the wet screenings is stated by Mr. Weand, who had, until recently, the contract for operation, to be about 63 lbs. per cubic foot and the cost of operation, including about 5 h. p. of steam power required for rotating the screen and driving a centrifugal separator, to be $1.00 per million gallons when taking 4 million gallons per day.

One difficulty, due to the fine mesh employed, is the frequent stoppage for repairs. This amounted to 1500 hours, equivalent to 63 days, in 1910, and an equivalent of 77 days in 1909. Screens of this type should always, therefore, be in duplicate.

Another objection in some cases would be the loss of several feet head caused by the drop in the sewage through the screen.[1]

A high percentage of moisture in the screenings is probably inevitable with fine meshes and domestic sewage. In his annual report for 1910 Mr. Ulrich says: "The criterion for screening efficiency should be the thoroughness with which the larger suspended matters are removed and not only mere bulk of removed matters. All materials large enough to clog sprinkler nozzles should be screened out, but it is more economical and just as satisfactory to remove finer solids by sedimentation."

[1] By a recently devised modification of design Mr. Weand hopes to save the greater part of this lost head.

It would appear, too, that with the constant agitation of the fecal matter by the wash water and the rotation of the screen, much of it will have become so finely broken up as to pass through with the sewage.

But in spite of these disqualifications, the local authorities are satisfied, on the whole, with the results secured and have recommended the installation of a second unit.

Screens of this general type are, or soon will be, installed at Atlanta, Ga., Brockton, Mass., New Brunswick, N. J. and Baltimore, Md.

Providence, R. I.—Here the screen bars are of wood 1 in. × 10 in. in section, spaced 3/4 in. apart, forming an inclined rack 69 ft. in length, inclined 17° to the vertical, through which the sewage—about 19.8 million gallons per day—flows, with a depth of from 2 to 5 1/2 ft., averaging about 3 ft. The screen is cleaned continuously by hand with rakes. The screenings, consisting chiefly of paper and rags, amounted, in 1910, to 208 lbs. or 28.6 lbs. of dry material, per million gallons of sewage. The wet screenings are placed in perforated cans about 18 in. in diam. × 20 in. in height, which weigh 30 lbs. each and hold about 230 lbs. of screenings, in which the material is removed.

Waterbury, Conn.—With a 1/2-in. mesh of galvanized wire, 140 lbs. or 0.08 cu. yd. of screenings were removed per million gallons of sewage.[1] The average composition of the screenings for the year ending November, 1906, was as follows:

TABLE VI

Composition of Screenings

	Parts per million		
	Total	Dissolved	Suspended
Oxygen consumed	46	26	20
Organic nitrogen	14.8	10.3	4.5
	Total	Fixed	Volatile
Suspended matter	165	115	50
Fats	26		
Particles in micro-suspension	84		
Colloidal matter	15.7		

[1] W. G. Taylor, *Eng. Rec.*, June 3, 1909.

Plainfield, N. J.—The volume of sewage is about 90 gallons per capita.[1] With screens having openings about 1/2 in. apart in the clear, 0.18 to 0.22 cu. yds. of screenings containing 85 per cent. of moisture are removed per million gallons of sewage.

Pawtucket, R. I.—The strong domestic sewage, amounting to an average of 0.277 million gallons per day in 1910, passes through one of a pair of rack screens 7.96 ft. wide×4.4 ft. high composed of wooden strips 3/4 in.×3 in. in size, spaced 5/8 in. apart. The depth of sewage passing the screen is about 2.1 ft. During 1910, 1036 cu. yds. of wet material were removed and buried in pits, amounting to 10.25 cu. yds. per million gallons. This large amount is accounted for in part by the fact that it includes a small amount of grit, which is pumpted out once a week from the depressed pit in front of the screen, together with the screenings, by an Edson diaphragm pump. Another reason lies in the strength of the sewage and to the fact that it enters the screen chamber 3 ft. below the surface of the liquid. The screenings consist of rags, paper, grease, fecal matter and kitchen wastes. During the interval between cleaning a mat of grease and other wastes frequently forms in the screen chamber, sometimes to the thickness of 18 in. or 2 ft., of sufficient strength to support a man, below which the material is much more dilute.[2]

TABLE VII

MATERIAL REMOVED BY SCREENS

	Cu. yds. wet screenings per million gal. sewage.	Lbs. dry solids per million gal. sewage	Per cent. of suspended solids in wet sludge. (By volume)		
			Total	Volatile	Fixed
Nov. 10, 1905–Feb. 23, 1906. .	7.53	746	5.68	4.45	1.23
Mar. 2, 1906–May 11, 1906. . .	5.83	549	5.44	4.36	1.08
Oct. 12, 1906–May 3, 1907. . .	8.96	792	5.22	4.15	1.07
Feb. 3, 1911–Mar. 24, 1911. . .	10.25	1024	5.89	5.45	0.44

IV. SLUDGE FROM PLAIN SEDIMENTATION

Massachusetts State Board of Health.[3]—Experiments were made with Lawrence (combined system) sewage during the years

[1] *Eng. News.*, Vol. LXIII, p. 541.
[2] George A. Carpenter, city engineer
[3] Rep. 1908, p. 454, *et seq.*

1892 to 1897, inclusive, by allowing it to settle while quiescent for 4 hours. Nearly 60 per cent. of the suspended matter and 33 per cent. of the total organic matter, as indicated by the albuminoid ammonia, were removed.

In 1906 a large tank was used for this purpose. The period of sedimentation varied from 2 to 14 hours, and in 2 1/2 years of operation there were removed about 44 per cent. of the suspended matter, as indicated by the albuminoid ammonia in suspension, "58 per cent. as shown by total solids, and 52 per cent. as shown by loss on ignition."[1]

Experiments have also been conducted since 1903 with the sewage of Andover, which passed at an average rate of 150,000 gallons per day through a tank holding 13,500 gallons, the average period of sedimentation being about 2 hours.

"The average removal of suspended matter by this tank was about 56 per cent. as shown by determinations of albuminoid ammonia in suspension, 71 per cent. as shown by total solids, and 70 per cent. as shown by loss on ignition." About 31 per cent. of the total organic matter was removed.

TABLE VIII

AVERAGE SOLIDS IN EFFLUENTS FROM TANKS. PARTS PER MILLION

	Total	Loss on ignition	Fixed
Experiment Sta., 1906–1908:			
Unfiltered	624	213	411
Filtered	549	156	393
In suspension	75	57	18
Andover., 1905–1908:			
Unfiltered	446	206	240
Filtered	388	158	230
In suspension	58	48	10

Between July and November 15, 1905, measurements of the sludge were made, giving 1.25 tons per million gallons of sewage. Between April 23 and November 15, 1906, when the daily flow varied from 75,000 to 350,000 gallons, about 2.28 tons of wet sludge were removed per million gallons of sewage, assuming

[1] Rep. 1908, p. 454, *et seq.*

the average flow to have been 175,000 gallons per day. This sludge lost 61 per cent. in weight by drying. Analyses of the dried sludge resulted as follows:

Organic matter	60 per cent.
Carbon	33 per cent.
Organic nitrogen	1.6 per cent.
Fat	24 per cent.

Worcester Experiments.—In 1903 a tank having a capacity of 344,000 gallons received an average of one million gallons of sewage per day, which was therefore subjected to 8 hours' sedimentation.

The suspended matter removed, as indicated by the albuminoid ammonia, averaged 40.80 per cent., and the total organic matter removed averaged 27.48 per cent. The resulting volume of sludge was 0.125 per cent. of the sewage, or about 6.17 cu. yds. per million gallons, and the water contained was 96.5 per cent. The cost of pressing this sludge into cakes was "$1.56 per million gallons of raw sewage, including handling of pressed cake by trolley to the sludge dump. The other costs of sedimentation, labor and attendance, are given as $1.85 per million gallons."[1]

The composition of this sewage was, in parts per million:

Free ammonia	17.69
Albuminoid ammonia,	
Total	8.32
Dissolved	2.88
Suspended	5.44
Oxygen consumed,	
Unfiltered	93.90
Filtered	53.60
Chlorine	90.40

Columbus Experiments.[2]—The two tanks used here were 8 ft. deep and 40 ft. long, and their effective capacity was about 17,000 gallons. The time of retention in these tanks was 8 hours in Tank A and 6 hours in Tank B, giving respective velocities of 4.9 and 6.7 ft. per hour (.42 and .56 mm. per second). The results were as follows when using raw sewage that had first passed through grit chambers:

[1] Geo. W. Fuller, *Trans. Am. Soc. C. E.*, Vol. LIV, Part E, p. 178.
[2] Rep. Sewage Purification, 1905. Johnson, pp. 88-91.

TABLE IX

RESULTS OF PLAIN SEDIMENTATION WITH RAW SEWAGE

	Tank A		Tank B	
	Influent	Effluent	Influent	Effluent
	Parts per million			
Period of operation	Aug., 1904 to June, 1905.		Nov., 1904 to April, 1905	
Oxygen consumed	46	37	47	39
Organic nitrogen	8.0	6.4	7.6	6.3
Free ammonia	11.7	11.7	11.3	11.0
Residue on evaporation:				
Total	950	875	927	857
Dissolved	803	797	793	784
Suspended	147	78	134	73
Volatile:				
Total	168	137	164	137
Dissolved	104	103	100	99
Suspended	64	34	64	38
Fixed:				
Total	782	738	763	726
Dissolved	699	694	693	685
Suspended	83	44	70	35

	Percentages of removal	
	Tank A	Tank B
Oxygen consumed	20	17
Organic nitrogen	10	17
Free ammonia	0	6
Residue on evaporation		
Total	47	46
Volatile	47	41
Mineral	53	50

With raw screened sewage containing about 210 parts per million of suspended matter, or 7 1/2 cu. yds. of sludge 87 per cent. water, the following results were obtained.[1]

[1] Rep. on Sew. Purif., Columbus, 1905. Johnson, pp. 151–153.

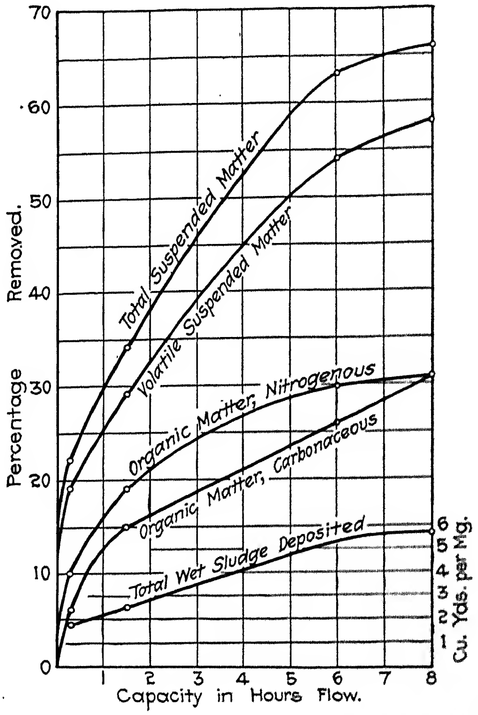

FIG. 39.—Results of sedimentation, Columbus. Reproduced by permission of the Metropolitan Sewage Commission of N. Y.

TABLE X

RESULTS OF PLAIN SEDIMENTATION WITH RAW SCREENED SEWAGE

	Tank A	Tank B
Period of sedimentation	8 hours.	6 hours.
Suspended matter removed:		
Total	66 %	63 %
Volatile	58 %	54 %
Total organic matter removed:		
Nitrogenous	31 %	30 %
Carbonaceous	31 %	26 %
Fats removed	50 %	
Average period of sedimentation	6.8 hours.	
Wet sludge per million gallons of sewage	5.75 cu. yds.	

Philadelphia Experiments.—Two tanks were first used. Tank No. 12 had a ratio of length to depth of 1.5:1 and a capacity of

9943 gallons, which was later reduced by sloping the bottom and adding a baffle and scum boards to 8738 gallons. Tank No. 13 had a ratio of length to depth of 2.5:1 and a capacity of 7767 gallons, later reduced as in the case of Tank No. 12, to 5475 gallons.

TABLE XI

RESULTS OF PLAIN SEDIMENTATION. TANKS 12 AND 13

Conditions	Hours storage		Suspended solids: Parts per million, Average effluent		Suspended solids: Per cent. removal	
	No. 12	No. 13	No. 12	No. 13	No. 12	No. 13
Flat unbaffled	6	6	55	66	65.5	59.2
Flat unbaffled	4 1/2	4 1/2	53	60	72.2	69.3
Sloping bottom baffle and scum	3 1/2	3 1/2	71	81	64.1	61
Sloping bottom baffle and scum	6	5.85	60	75	67	58.7

Tank No. 17 had a ratio of length to depth of 4.

TABLE XII

RESULTS OF PLAIN SEDIMENTATION. TANK 17

Conditions	Hours storage	Suspended solids: Parts per million Average effluent	Suspended solids: Per cent. removal
Unbaffled	10	65	50.4
Unbaffled (stronger sewage)	6	About 65	67.5
Unbaffled	4	44	81.2
Baffles and scums	4	59	72.5
Baffles and scums	10	46	74

The conclusion drawn from these experiments was that "long storage periods are unnecessary for efficient sedimentation and that great improvement in the uniformity of the tank liquor is obtained by efficient baffling, creating uniform velocity over the entire area of the cross section."

A heavy scum formed on Tank No. 13, which received unscreened sewage. After introducing baffles this formed to a thickness of 2 ft., amounting to 5.6 cu. yds., weighing 5 tons.

It contained 1810 lbs. of dry solids and 260 lbs. of fat, and was very offensive when punctured or removed.

The average composition of the sludge was as follows:

TABLE XIII

COMPOSITION OF SLUDGE

Tank No.	12	13	17
Sewage	Screened	Crude	Crude
Wet sludge:			
Specific gravity	1.036	1.053	1.043
Per cent. moisture	90	86.1	87.7
Per cent. of dry residue:			
Volatile	49	48	50
Fixed	51	52	50
Nitrogen	1.3	1.4	1.3
Fat	8.1	7.4	7.2

The sludge from Tank No. 12, which had been fine-screened, was uniform and with no particle over 1 mm. diameter. It therefore flowed much more freely than that from Nos. 13 and 17, which contained fibers of wool and hops.

Scum formed in irregular amounts in these tanks before placing scum boards, but after this was done it formed promptly and increased to a considerable thickness at the inlet end of the tank, being tough and tenacious.

The following is a typical analysis of this material when formed on crude sewage:

Average characteristics of scum from Tanks No. 13, No. 17 and No. 19 (Emscher).

Specific gravity	1.05	per cent.
Moisture	82.5	per cent,
Dry residue	17.5	per cent.

The average composition of the dry residue was:

Volatile matter	60.5	per cent.
Fixed	39.5	per cent.
Nitrogen	1.7	per cent.
Fats	13.5	per cent.

No scum of this kind formed on Tank No. 12.

The fact that the scum floats in spite of its high specific gravity

is explained by the presence of entrained bubbles of gas which, when liberated on removal, produced an offensive odor.

Reading, Pa.—Sedimentation here for 15 hours removed 123 of the 165 parts per million of suspended matter.[1] During 1910 a sedimentation tank at Millmont received 1425 million gallons of sewage.

Three and three-tenths cubic yards per million gallons were removed with 10 hours' retention and a flow of 3 million gallons per day through a tank 250 ft.×50 ft.×16 ft. in size. The composition of the sludge was:[2]

Moisture	91.83 per cent.
Mineral matter	2.83 per cent.
Volatile matter	5.34 per cent.

The tank was cleaned 6 times during the year, but at no time have there been seriously objectionable odors from the sludge.

Kinnicutt, Winslow and Pratt give the following comparison of the results obtained by plain sedimentation at Plainfield, N. J.; Columbus, O., and Reading, Pa.

Results of Plain Sedimentation

	Period of sedimentation	Suspended solids		Per cent.
		Parts per million		
	Hours	Influent	Effluent	Reduction
Plainfield, N. J.	10.0	118	54	54
Columbus, O.	13.0	304	101	67
Reading, Pa.	15.0	165	42	75

V. Septic Tank Sludge

Massachusetts State Board of Health.[3]—Experiments with septic tanks have been conducted at Lawrence since 1898 and with Andover sewage from July, 1899, to July, 1902. In five series[4] of experiments the analyses of the sewage and effluent varied between the following limits:

[1] Kinnicutt, Winslow and Pratt.
[2] *Eng. Rec.*, Vol. LXII, p. 186.
[3] Rep. 1908, p. 476, *et seq.*
[4] A sixth series in which sludge was used in place of sewage is omitted.

TABLE XIV

SUSPENDED MATTER IN SEWAGE AND EFFLUENT

	Parts per million	
	Entering sewage	Tank effluent
Unfiltered: Total	646–912	493–571
Loss on ignition	323–464	175–232
Filtered: Total	475–537	448–510
Loss on ignition	174–199	126–173

In Tank A, 70 per cent. of the total suspended matter and 70 per cent. of the suspended organic matter received during 6 1/4 years were deposited, and of this 82 per cent. of the total and 88 per cent. of the organic suspended matter were destroyed. Again, during a period of 4 1/2 years, 66 per cent. of the total suspended matter and 66 per cent. of the suspended organic matter were deposited, and of this about two-thirds of the total and 80 per cent. of the suspended organic matter were destroyed by digestion. The period of sedimentation averaged in the first case, about 12 hours, and in the second case, 15 hours.

In Tank G, in which the period of sedimentation was about 6 hours, 60 per cent. of both the total and organic suspended matter was deposited.

In Tank H, with 18 hours' storage, 75 per cent. of the total and 78 per cent. of the suspended organic matter were deposited, while 84 per cent. of the total and 90 per cent. of the organic matter which deposited were destroyed.

In Tank F, which received a sewage with about 50 per cent. more suspended matter than Tank A, and more than twice that of Tanks G and H, 76 per cent. of the total and 82 per cent. of the organic suspended matter were deposited, while of this, 71 per cent. of the total and 86 per cent. of the organic matter were destroyed.

Tank B received a sewage about 10 times as strong as G and H. Here 82 per cent. of the total and 84 per cent. of the organic suspended matter were deposited, and 74 per cent. of the total and 82 per cent. of the organic suspended matter in this were destroyed.

TABLE XV

COMPOSITION OF DRY SEPTIC TANK SLUDGE

	Per cent.	Number of tanks from which sludge was sampled
Mineral matter	45.6 to 70.9	6
Total organic matter	54.4 to 29.1	6
Organic nitrogen	1.1 to 2.9	6
Fats	8.8 to 11.9	4
Carbon	25.1 to 29.8	3
Hydrogen	3.0 to 4.0	3

Madison, Wis.—Here, by septic tank treatment, 42.8 per cent. of the suspended solids and 60.8 per cent. of the albuminoid ammonia are removed.[1]

TABLE XVI

SUMMARY OF RESULTS SHOWING ACCUMULATION AND LIQUEFACTION OF SLUDGE

Septic tank	A	B	C	D	E.
Period of service 1904–5	Aug. 16 to June 30	Aug. 16 to June 30	Nov. 22 to June 30	Feb. 18 to June 30	Mar. 9 to June 30
Days in service	300	301	221	132	118
Total million gallons of sewage treated	9.5	5.7	10.8	4.1	0.79
Average period of flow (hours)	13.9	21.8	8.0	4.0	8.0
Average velocity of flow millimeters per second	0.24	0.15	0.42	0.84	0.14
Tons dry solids per million gallons:					
In applied sewage	0.61	0.61	0.62	0.86	1.21
Deposited in tank	0.31	0.31	0.28	0.26	0.67
Escaped in effluent	0.30	0.30	0.34	0.66	0.54
Tons dry solids per million gallons:					
Deposited[2]	0.40	0.40	0.36	0.33	0.86
In tank at end of tests	0.21	0.29	0.12	0.20	0.43
Per cent. solid matter liquefied	48	28	67	39	50
Cubic yards wet sludge per million gallons sludge treated found in tank at end of test.	1.4	1.8	0.8	1.5	2.9

Columbus Experiments.—Five septic tanks were used in the Columbus experiments. Tanks A, B, C and D received the effluent from the grit chamber, and A received the sewage after screening. Tanks A, B and C were 8 ft.×40 ft. in plan with

[1] Purification with special ref. to Wis. conditions. Geo. J. Davis, Jr., and J. T. Bowles. *Bul. Univ. Wis.*, Oct., 1909.

[2] Corrected in ratio of 28 to 36 to correspond to ratio of computed deposit to actual deposit respectively in plain sedimentation Tank A.

an effective capacity of 17,000 gallons. Tank D was circular, 12 1/2 ft. in diameter, with an effective depth of 5 1/2 ft. It was baffled so as to make the length of flow 40 ft. and had an effective capacity of about 5370 gallons, and was covered. Tank E was a cylindrical boiler shell 6 ft. diameter by 15 ft. long, air-tight, with a 1/2-in. gas pipe leading to a meter. The effective depth was 5 ft. and the capacity 7200 gallons.

In general, it may be assumed that in Tanks A, B and C the average accumulated deposit amounted to 1.33 cu. yds. per million gallons as compared with 3.3 cu. yds. per million gallons with plain sedimentation. The percentage liquefied was therefore about 60. The 50 per cent. liquefied with crude sewage in Tank E was believed to be a fair average to use in estimates.

The composition of the resulting septic sludge was found by analysis to be as follows:

TABLE XVII

COMPOSITION OF SEPTIC TANK SLUDGE

Tank	A	B	C	D	E
Weight of wet sludge, pounds per cubic yards	1836	1823	1823	1800	1833
Specific gravity	1.089	1.080	1.080	1.069	1.087
Water, per cent	83.3	82.3	83.2	84.7	83.7
Solids, per cent	16.7	17.7	16.8	15.3	16.3
Volatile matter, per cent	4.4	4.4	4.3	4.1	5.0
Nitrogen	0.25	0.25	0.23	0.19	0.18
Fats	0.91	1.06	1.05	1.36	1.17

The reduction of suspended matter secured at Columbus during the years 1909 and 1910 by septic tank-treatment was as follows:

TABLE XVIII

REDUCTION OF SUSPENDED MATTER[1]

	Maximum		Minimum		Mean	
	1909	1910	1909	1910	1909	1910
Daily volume of sewage, million gallons	21.4	17.9	3.1	2.5	11.1	12.9
Period of flow through tank, hours	36.0	17.0	4.3	3.5	10.1	7.2
Total suspended matter, parts per million:						
Screened sewage	1088	630	13	16	201	211
Septic effluent	230	264	12	9	82	80

The per cent. suspended matter removed was, in 1909, 58, and in 1910, 62.

[1] Furnished by W. W. Jackson, Supt. Water Works.

Pawtucket, R. I.[1]—In 1900, 41.5 per cent. of the organic matter was removed by the tanks. At the end of 10 months' operation the accumulation of sludge was 5.428 cu. yds. per million gallons with 81.75 per cent. moisture. The dried solids amounted, therefore, to 0.99 cu. yds. per million gallons of sewage. 377.33 parts per million, or 1.868 cu. yds. of mineral matter were deposited in the tank for each million gallons of sewage. The amount of dried solids removed by septic action was, therefore, 1.87 − 0.99 = 0.88 cu. yds. per million gallons. The cost of its removal was 41 1/3 cts. per cubic yard. This treatment has now been discontinued.

Mansfield, O.[2]—The sewage from about 10,000 persons, 40 per cent. of which is collected by the separate system and which is much diluted with ground water, flows at a rate of about one million gallons per day through bar screens with 3/4-in. openings, and is then settled in 4 septic tanks 92 ft. 3 in. ×52 ft. in plan, having an effective depth of 7 ft. and a combined capacity of 1 million gallons.

The crude influent sewage contains but 34 to 42 parts per million of suspended matter, and the effluent contains 34 parts per million, showing very little reduction. The following is a more recent analysis. Parts per million of suspended matter:

	Total	Volatile
Crude sewage	74	55
Septic effluent	85 to 135	43 to 54

The sludge resulting from 4 years' operation weighed 1868 lbs. per cubic yard. It had a specific gravity of 1.11, and contained:

Moisture	80.8 per cent.	Nitrogen	1.03 per cent.
Volatile matter.	3.6 per cent.	Fats	4.7 per cent.

It was granular in structure and not offensive when removed from the tanks. Exposed in thin layers for about 4 days the black color, due to ferric sulphide, disappeared, leaving the material similar to humus.

The cost of disposal for the 1200 cu. yds. of sludge removed was about 50 cts. per cu. yd.

Plainfield, N. J.[3]—The population of 20,550 persons furnishes

[1] Rep. of City Eng'r for year ending Sept. 30, 1900.
[2] Rep. St. Bd. Hlth., 1908.
[3] *Eng. Rec.* Vol. LXIV, p. 29.

about 1.9 million gallons per day of domestic sewage to 4 septic tanks having a combined capacity of 1.35 million gallons.

In March, 1910, 1600 cu. yds. of wet sludge and scum were removed, equivalent to 3.35 cu. yds. per million gallons of sewage treated during the previous 11 months.

In March, 1911, 1650 cu. yds. of wet sludge and scum were removed, equivalent to 3.01 cu. yds. per million gallons of sewage treated during the previous year.

No objectionable odors were given off except while the tanks were being emptied.

In 1910 the average suspended matter, in parts per million, was as follows:

In screened sewage 152, varying from 114 in February to 271 in November.

In septic effluent 56, varying from 42 in May to 72 in December.

The percentage of removal was, therefore, 64.5.

The fats averaged 42.8 parts per million in the screened sewage, and 27.7 parts per million in the septic effluent, the percentage of removal being about 35.

Waterbury, Conn.[1]—Observations were made here of the results obtained with two septic tanks 14 ft. ×6 ft. 3 in. ×6 ft. in size, of a capacity of nearly 4000 gallons each, beginning in June, 1905, and lasting 18 months. The time allowed for sedimentation varied from 8 to 33 hours, and the results were as follows:

TABLE XIX

REMOVAL OF SOLIDS IN SEPTIC TANKS

	Tank No. 2	Tank No. 3
Average period of sedimentation. Hours	15.5	11
Horizontal vel. in mm. per sec	0.08	0.11
Wet sludge in tank. Cu. yds. per million gallon sewage.	1.07	0.55
Dry solids deposited. Tons per million gallon sewage.	0.25	0.25
Per cent. retained in tank	56	36

[1] *Eng. News*, Vol. LXI, p. 596.

TABLE XX

COMPOSITION OF SEPTIC SLUDGE AND SCUM IN TERMS OF THE WET MATERIAL

	Sludge		Scum
	Tank No. 2	Tank No. 3	Tank No. 2
Pounds per cubic yard	1721	1738	1637
Specific gravity	1.02	1.03	0.97
Moisture, per cent	86.3	85.4	80.9
Total solids, per cent	13.7	14.6	19.1
Volatile, per cent	5.9	7.	8.9
Nitrogen, per cent	0.16	0.22	0.34
Fats, per cent	1.53	1.52	2.00

Saratoga, N. Y.[1]—The volume of flow amounted in 1904, to from 1 1/4 to 2 1/2 million gallons daily of weak domestic sewage, the population varying from 12,000 in winter to 50,000 in summer.

COMPOSITION OF SEWAGE

	Parts per million
Free ammonia	20
Albuminoid ammonia	4
Oxygen consumed	50
Suspended solids	200

There are 4 septic tanks 91 1/2×51 1/2 ft., holding 8 ft. depth of sewage, or with a total capacity of 1,000,000 gals.

The period of retention of sewage was 10 to 15 hours. From July, 1903, until January, 1905, no sludge was removed from septic tanks.

The following shows the results of the treatment:

Total dry solids received	500 tons.
Dry solids passed in effluent	175 tons = 35 per cent.
Dry solids in tank, Jan. 1, 1905	100 tons = 20 per cent.
Dry solids removed by digestion	225 tons = 45 per cent.

[1] *Eng. Rec.*, Vol. LI, p. 84 and *Rep. N. Y. Dept. Hlth.*, 1907, Vol. II.

The composition of the sludge and scum was as follows:

	Sludge	Scum
Wet material:		
Specific gravity	1.025	0.975
Moisture	94.0 per cent.	86.5 per cent.
Dry residue:		
Volatile	4.5 per cent.	10.0 per cent.
Fixed	1.5 per cent.	3.5 per cent.

VI. Sludge from Emscher Tanks

Philadelphia Experiments.—Experiments were made in Philadelphia with an Emscher tank 5 ft. in diameter and 10 ft. deep. The conical bottom inclined 30 degrees to the horizontal. By a cylindrical baffle, the motion of the sewage was first downward from the annular influent channel surrounding the central vent and then upward to the effluent at the periphery—about 4 1/2 ft. in each direction. The sludge chamber was about 4 ft. in effective depth. The time of passage was about 2 hours. During 3 months' use (Jan. 12 to April 13, 1910) 53 per cent. of the suspended solids were removed, leaving in the effluent 92 parts per million.

The sludge produced had the following characteristics:

Wet sludge:	
Specific gravity	1.085
Moisture	82.5 per cent.
Volume per million gals. of sewage	0.9 cu. yds.
Dry residue:	
Volatile	38 per cent.
Fixed	62 per cent.
Nitrogen	1.2 per cent.
Fats	6.5 per cent.

The results obtained are not strictly comparable with those from a tank of the 30 ft. depth recommended by Dr. Imhoff. The deeper tank would produce a sludge with less moisture and with a larger amount of entrained gas, which would be of subsequent value in assisting the process of drying.

The evolution of gas appears to have been quite active in the sludge chamber. It was inodorous and presumably composed chiefly of methane (CH_4).

As withdrawn from the tank the sludge was "fine, granular and homogeneous; considering its relative dryness, it flowed freely and did not have an offensive odor. When withdrawn from the sludge outlet, the odor was decidedly 'tarry,' and after a few days the dried mass was inodorous." The solids appeared to have been completely digested.

The composition of the scum was as follows:

Wet sludge:	
Specific gravity	1.05
Moisture	87.2 per cent.
Dry residue:	
Volatile	61.8 per cent.
Fixed	32.8 per cent.
Nitrogen	1.9 per cent.
Fats	14.3 per cent.

Chicago Experiments.[1]—Experiments with the Emscher tank have been carried on by the Chicago Sanitary District.

The total depth of the circular tank was 17 ft. and the inside diameter 7 ft. 6 1/2 in. An 18-in. central vent pipe was supported by a conical hood separating the two chambers and a cylindrical baffle caused the sewage entering near the central vent to descend to a depth of at least 3 ft. from the surface and then rise to the opening leading to the 2-in. effluent pipe. The sludge chamber had a total depth of 12 ft. 3 in., the lower 4 ft. forming a cone with a slope of 45 degrees.

The sewage flow amounted to 48,500 gallons per day from May 26 to June 7, 1910, 31,000 gallons per day from June 8 to Sept. 12, and then 13,500 gallons per day to Nov. 1. It was first passed through a 5/8-in. screen and then pumped from mid-depth at the screen chamber through 40 ft. of force main and a grit chamber to the tank. The time of passage through the tank was about 2 hours, the latter part of the time the capacity of the upper chamber being 1175 gallons. The reduction of suspended matter was from 64 per cent. to 69 per cent. after the operation was well established. About 2 cu. yds. of sludge were produced

[1] George M. Wisner, Chief Engineer, and Langdon Pearse, Assistant Engineer, the Sanitary District of Chicago.

per million gal. of sewage during the summer and fall of 1910, having the following characteristics, and 0.93 cu. yds. per million gallons of completely digested sludge per million gallons during a period of 5 months.[1]

Wet sludge:	
Specific gravity	1.04
Moisture	86 to 90 per cent.
Dry residue:	
Volatile matter	39 per cent
Fixed matter	61 per cent.

With prolonged operation, and where the sludge chambers are of sufficient depth, any mixing of the top and bottom layers of sludge will be prevented and there will be a gradual movement downward toward the bottom. As the sludge approaches the outlet, the organic ingredients are more and more decomposed so that a more favorable condition, when discharged, may be expected than in the case of the comparatively small experimental plants at Philadelphia and Chicago.

The following table gives comparative data for several plants in the Emscher district.[2]

TABLE XXI

RESULTS OF TREATMENT IN THE EMSCHER DISTRICT

	Recklinghausen		Bochum		Essen-N. W.	
	Sewage	Effluent	Sewage	Effluent	Sewage	Effluent
Suspended solids:						
Total	466.6	127.5	402.0	93.3	449.8	135.4
Organic	259.3	73.5	186.9	56.4	261.6	85.6
Mineral	207.3	54.0	215.1	36.9	188.2	49.8
Average percent. removal of total suspended solids.	72		77		70	
Period of sedimentation, hours	3/4-1 1/4		1-1 1/2		1/2-1	
Sludge, cubic yards per million gallons.	1.65		2.1		1.39	
Per cent. moisture in sludge	82.9[3]		78.1		75.6	

In comparing these results with those obtained at Philadelphia, the German plants are seen to handle a much denser sewage combined with a lower percentage of moisture in the sludge resulting from briefer periods of sedimentation. It should be remembered, too, that the sewage in the Emscher District

[1] Rep. on Sew. Disp., Chicago, Geo. M. Wisner, 1911.
[2] *Technisches Gemeindeblatt.*, Mar., 1911. *Eng. News*, Vol. LXV, p. 663.
[3] The sludge space at Recklinghausen is insufficient for complete decomposition.

includes large volumes of trade wastes. For these reasons further experience under normal American conditions, and with full-sized plants, are necessary before the true relative value of this process can be established.

In a paper presented by Mr. Charles Saville[1] to the Boston Society of Civil Engineers,[2] he states that from 65 to 75 per cent. of the suspended solids in the sewage are usually removed. The scum formed is generally of small amount and quite odorless. It requires loosening with a rake once a month or so, to permit the escape of gas and allow much of it to deposit, but about once a year it becomes necessary to remove the scum from the surface.

The sludge is drawn off at intervals of from 2 weeks to 6 months, preferably the more frequent period. This should not be done by suction as this removes the entrained gases which it is desirable to retain incorporated with the sludge until placed on the drying bed; nor should withdrawal be so rapid as to permit the formation of a cone at the surface and the consequent entrance of sewage, as described by Elsner. The effluent pipe should then be filled with water or sewage to prevent the formation of an interior crust and consequent clogging with the next dose of sludge.

The energy with which digestion takes place probably depends to a great extent on the temperature. In the Emscher District the temperature in the sludge chamber remains practically between 55° and 63° even in winter. If the tanks were above ground or in a much colder climate the sludge chamber would probably have to be of greater capacity on account of the decreased bacterial activity.

In the design of Emscher tanks the space required for sludge storage should be approximately known. Until more is known regarding the rate of progressive concentration, due to digestion, it will be safe to assume the volume of the sludge during storage a mean between that required for fresh sludge and that finally produced by the Emscher tank from the sewage treated during the assumed period of storage. The volume of fresh sludge and the period of retention may be assumed from the data already given in the discussions by Dr. Elsner and Dr. Spillner.

If we assume 80 per cent. moisture in Emscher sludge and 90

[1] Associated with the firm of Hering and Gregory. Formerly with the *Emschergenossenschaft* at Essen.

[2] Dec. 28, 1910.

per cent. in freshly settled sludge, the latter will occupy twice the volume of the former, and an equal mixture will occupy 1 1/2 times the volume of Emscher sludge when completely digested. Therefore, if:

v = flow of sewage in gallons per capita per day
V = total daily flow of sewage
P = population served
D = days' retention of sludge
C = effective capacity of digestion chamber in cubic feet,

Then, for combined sewage, $C = 10{,}500\ \dfrac{DV}{v} = 10{,}500\ PD$, and

for separate sewage, $C = 5{,}250\ \dfrac{DV}{v} = 5{,}250\ PD$.

If we know the parts per million of suspended solids that may be expected to settle out from a known sewage in its passage through the sedimentation chamber and if we accept the estimate of Spillner and Blunk (see page 177), as to the reduction in the volume of sludge by its passage through the digestion chamber of the Emscher tank and by subsequent air-drying, there will result the quantities given in the following table.

TABLE XXII

VOLUME OF SLUDGE AND AIR-DRIED SLUDGE PER MILLION GALLONS OF SEWAGE OF DIFFERENT DENSITIES FROM SEPARATE SYSTEMS RESULTING FROM EMSCHER TANK TREATMENT

Suspended solids in sewage deposited parts per million	Cubic yards fresh sludge		Cubic yards Emscher sludge moisture 75 per cent.[1]	Cubic yards spadable air-dried sludge[2]
	Moisture 95 per cent.	Moisture 90 per cent.		
25	2.48	1.24	0.40	0.16
50	4.95	2.48	0.79	0.32
75	7.43	3.72	1.19	0.48
100	9.90	4.95	1.58	0.63
125	12.38	6.19	1.98	0.79
150	14.85	7.43	2.38	0.95
175	17.33	8.17	2.77	1.11
200	19.80	9.90	3.17	1.27
225	22.28	11.14	3.56	1.42
250	24.75	12.38	3.96	1.58
275	27.23	13.12	4.35	1.74
300	29.70	14.85	4.75	1.90

[1] Equals 16 per cent. of sludge with 95 per cent. moisture.
[2] Equals 40 per cent. of Emscher sludge.

Imhoff gives the sludge produced by the combined sewage of Bochum as 0.2 liters, or 0.007 cu. ft. per capita daily.[1] If v = the sewage flow per capita daily, the sludge resulting from each million gallons of combined sewage will be $7000/v$ cu. ft., or $260/v$ cu. yds. The sludge resulting from separate sewage, Dr. Imhoff says, is about half as much. With these assumptions, the following table of sludge volumes, which was prepared by Mr. John H. Gregory for the Metropolitan Sewerage Commission, of New York, gives the sludge output that will require final disposal.

TABLE XXIII

SLUDGE PRODUCED BY THE EMSCHER TANK WITH SEWAGES OF DIFFERENT STRENGTHS

Sewage flow gallons per 24 hours	Volume of sludge			
	Separate system 0.0035 cu. ft. per capita per day = 3.5 cu. ft. per 1000 pop. per day.		Combined system 0.007 cu. ft. per capita per day = 7.0 cu. ft. per 1000 pop. per day	
Per capita	Cubic feet per million gallons	Cubic yards per million gallons	Cubic feet per million gallons	Cubic yards per million gallons
50	70	2.6 −	140	5.2 −
60	58 +	2.2 −	117 −	4.3 −
70	50	1.9 −	100	3.7
75	47 −	1.7 +	93 +	3.5 −
80	44 −	1.6 +	88 −	3.2 +
90	39 −	1.4 +	78 −	2.9 −
100	35	1.3 −	70	2.6
110	32 −	1.2 −	64 −	2.4 −
120	29 +	1.1 −	58 +	2.2 −
125	28 +	1.0 +	56	2.1 −
130	27 −	1.0 −	54 −	2.0
140	25	0.93	50	1.9 −
150	23 +	0.86	47 −	1.7 +
160	22 −	0.81	44 −	1.6 +
170	21 −	0.76	41 −	1.5 +
175	20	0.74	40	1.5 −
180	19 +	0.72	39 −	1.4 +
190	18 +	0.68	37 −	1.4 −
200	17 +	0.65	35	1.3

[1] Wasser und Abwasser, Feb. 4, 1911, p. 446.

VII. Sludge from Chemical Precipitation

Massachusetts State Board of Health.[1]—A large number of experiments have been made by the Massachusetts State Board of Health on chemical precipitation. These indicate that by the proper use of copperas, ferric sulphate or alum, all the suspended matter and from 25 to 43 per cent. of the soluble organic matter of sewage as indicated by albuminoid ammonia may be removed.

"Using equal values of the different precipitants, applied under the most favorable conditions for each, upon the same sewage, the best results were obtained with ferric sulphate. Nearly as good results were obtained with copperas and lime, while lime or alum alone gave somewhat inferior effluents."

During the 5 years, beginning with 1893, sewage was treated with 1000 lbs. sulphate alumina per million gallons, and allowed 4 hours for sedimentation. As a result there was removed:

Total albuminoid ammonia, 56 per cent., varying from 50 to 63 per cent., in different years.

Albuminoid ammonia in suspension, 78 per cent., varying from 72 to 83 per cent. in different years.

Fats, 59 per cent., varying from 47 to 80 per cent. in different years.

Worcester, Mass.[2]—The sewage in 1910 averaged 14.57 million gallons per day (or 107.2 gallons per capita), including 3.47 million gallons of infiltration and a large amount of factory waste, rendering it decidedly acid. Of this volume an average of 9.81 million gallons of sewage per day were treated with 989 lbs. of lime per million gallons. After from 6 to 12 hours of precipitation,[3] the sludge produced amounted to 22 cu. yds. per million gallons, representing 77.8 per cent. of the suspended organic matter. This is drawn off by a floating arm and raised by Shone ejectors to a storage tank where 30 to 50 lbs. of lime per thousand gallons is added in the form of milk of lime. 15 or 20 per cent. of the supernatant liquid is drawn off to sand filters and the heavy sludge pumped under a pressure of 80 lbs. per square inch to filter presses. When pressed, this produces 3.69 tons of

[1] Rep. Purification of Sewage and Water, 1890, p. 786. An. Rep., 1908, p. 457.

[2] An. Rep. Supt. of Sewers, 1909-10.

[3] There are six primary tanks, operated in series, 100 ft. × 66 2/3 ft. × 7 ft. in size with a capacity of 350,000 gallons and 10 secondary tanks, operated in parallel, 166 2/3 ft. × 40 ft. × 7 ft. in size with a capacity of 350,000 gallons.

sludge cake per million gallons, which is taken by cars 3/4 of a mile and dumped on low-lying ground.

It has not been found economical to reduce the moisture by pressing as low as 60 per cent., but rather to let the cakes dry on the dump.[1]

The results of precipitation are shown by analysis as follows.

RESIDUE ON EVAPORATION

	Parts per million		Per cent. removed
	Ave. sewage	Ave. effluent	
Total:			
Total	789	697	11.7
Dissolved	545	637	−16.9
Suspended	244	60	75.4
Volatile:			
Total	367	300	18.3
Dissolved	228	271	−18.9
Suspended	139	29	79.1
Fixed:			
Total	422	397	59.2
Dissolved	317	366	−15.4
Suspended	105	31	70.5

TABLE XXIV

RESULTS OF CHEMICAL PRECIPITATION AT WORCESTER, MASSACHUSETTS

	Year ending Nov. 30, 1910	Ten years, 1901–10		
		Maximum	Minimum	Average
Moisture in wet sludge, per cent	91.80	94.75	90.20	92.39
Moisture in sludge cake, per cent	68.4	73.0	67.8	69.4
Tons solids per million gallons sewage treated.	1.17	1.74	0.99	1.37
Pounds lime added per 1000 gallons sludge.	53.5	53.5	20.0	40.7
Cost of operation:				
Per million gallons sewage	$4.53	$6.33	$3.85	$5.05
Per ton solids	$3.88	$4.33	$3.39	$3.74

[1] An. Rep. Supt. Sewers, 1898–99.

Providence, R. I.—The average volume of sewage treated per day for the year 1910 was 14,652,329 gallons. The total sewage produced was about 15 million gallons per day, and the population served was 199,000, making 75 1/2 gallons of combined sewage per capita. This contains wastes from wool-washing, dyeing, bleaching and jewelry works, and its analysis shows the following albuminoid ammonia in parts per million: Suspended, 4.84; soluble, 4.68. Total, 9.52.

This was treated with 485.5 lbs. of lime per million gallons, removing 48.32 per cent. of the organic matter (as albuminoid

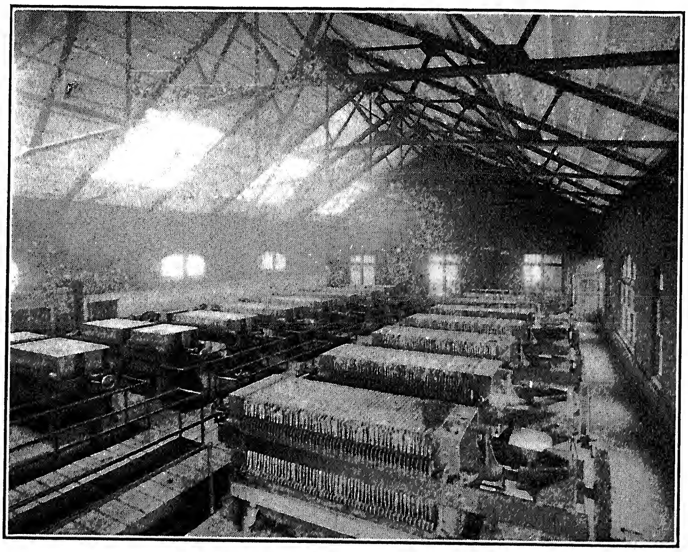

FIG. 40.—Sludge presses, Providence.
(Courtesy of Mr. O. F. Clapp, City Engineer.)

ammonia), and 82.64 per cent. of the suspended matter. The sludge amounted to 23.15 cu. yds. per million gallons and contained 92.07 per cent. moisture.

Sedimentation takes place, first, in 4 primary tanks 11.87 ft. deep and then in 16 secondary tanks 8.67 ft. deep, whose aggregate effective capacity is 11.13 million gallons. About 93 per cent. of the sludge is removed by the primary tanks, so that at times it has been possible to omit the use of the secondary series. The sludge is forced under a pressure of about 70 lbs. per square inch to 18 presses holding from 43 to 54 plates, each 36 in.

square, by which it is pressed into cake from 3/8 to 1 1/4 in. thick. About 5.61 tons of cake per million gallons of sewage are produced, or 0.24 ton per cubic yard of wet sludge. The pressed cake contains 72.4 per cent. moisture. Forty-seven pounds of lime per thousand gallons were added to the sludge before pressing. Two men working together will remove about 50 tons of cake from the presses in 10 hours. Ordinarily, eight men are employed on 16 presses.

The cost of chemical precipitation in 1910 was $3.11 per million gallons of sewage, and that of sludge disposal, $4.06, making the total cost $7.17. The sludge pressing cost $2.62 per ton of solids.

Alliance, Ohio.[1]—About 1.6 million gallons of sewage per day were received by a separate system of sewers from 6500 persons in 1907 and passed though 2-in. and 1/4-in. bar screens to 3 precipitation tanks, 80 ft.×40 ft.×6 ft. in size, having a total capacity of 420,000 gallons. The sludge is pressed, reducing the moisture from 88 per cent. to 47 per cent., 1500 tons of wet sludge furnishing 60 tons of pressed cake, or 2.5 tons of cake per million gallons of sewage. The sludge cake is usually taken away by farmers for fertilizer.

The cost of operation was, in 1906, 45 cts., and in 1907, 55 cts. per capita.

Canton, Ohio.[1]—About 2 1/2 million gallons of domestic sewage were contributed daily in 1908 by a population of about 23,500. After passing a screen rack 2 ft. 6 in.×4 ft. 2 in. in size, inclined 20 degrees to the vertical, and composed of 3/16 in.×1 1/4 in. bars, set 7/8 in. apart, the sewage, which contains but 43 parts per million of suspended matter on account of the large proportion of ground water, is treated with about 13.6 grains of lime per gallon (1 ton per million gallons) on week days, and half this amount on Sundays. It then passes to a series of 4 tanks 100 ft.×50 ft.×5 ft. in size, having a total capacity of 700,000 gallons, for precipitation. The surface velocity was measured in the first of these tanks and found to be 41 ft. per minute. In the other three tanks it was 27.8 ft. per minute.

The period of retention was 6.7 hours. The first two tanks are cleaned 3 times a week, the last two 2 times a week. The sludge is pumped to neighboring fields and plowed under, but this mode of disposal has not proved satisfactory.

[1] Rep. State Board of Health, 1908.

The cost of operation in 1901 was $3850, which, at 2 1/2 million gallons per day, would be $4.22 per million gallons.

In winter, with plain sedimentation, 13.7 cu. yds. of wet sludge were removed in this way per million gallons of sewage, while in warm weather, with chemical precipitation, the amount removed was 14.3 cu. yds. per million gallons. The suspended solids, which amounted to about 86 parts per million, were reduced by about one-half in each case, and with chemical precipitation the total organic matter was reduced by about the same amount. The greater part of the sedimentation took place in the first tank.

The results of several analyses are given in the following table:

TABLE XXVI

REMOVAL OF SUSPENDED MATTER AT CANTON

	Parts per million				Per cent. removed		Tons of dry solids removed per million gallons sewage
	Total		Volatile				
	Sewage	Effluent	Sewage	Effluent	Total	Volatile	
Plain sedimentation:							
Jan. 16, 1907	83	41	42	29	51	31	0.175
Feb. 26, 1907	124	61	62	28	51	55	0.263
Chemical precipitation:							
Aug. 9, 10, 1906	43	42	31	30	2	3	0.004
July 17, 1907	89	51	47	40	45	17	0.158
July 18, 1907	118	58	65	30	51	54	0.250

Although about 50 per cent. of the organic matter is removed, the effluent is unstable and not entirely satisfactory, and the extra cost, due to the use of chemicals, does not appear to be justified by the results.

The annual cost of operating the works is about 15 cts. per capita of population.

White Plains, N. Y.[1]—This plant, operated under the patent process of J. J. Powers, will soon be discontinued owing to the construction of the Bronx Valley trunk sewer. In 1907 there were nearly 14,000 persons contributing about 850,000 gallons of strictly domestic sewage daily.

[1] Rep. N. Y. State Bd. of Hlth., 1907.

This passed through a vertical screen of 1/8 in. × 1/2 in. bars 4 ft. long spaced 1 in. center to center, to a sedimentation chamber 45 ft. × 24 ft. in size; 5 or 6 barrels (1200 to 1300 lbs.) of lime were added daily with a varying amount of perchloride of iron—frequently a carboy (140 lbs.) a day.

When removing sludge, once a week, the tank is disinfected with chlorine, as described hereafter for the East New York plant.

The sludge, amounting to about 35 cu. yds. per week, or 5.9 cu. yds. per million gallons of sewage, is pumped to 2 drying beds having an area of about 3600 sq. ft. After drying, a small part of this is utilized as a fertilizer.

The annual cost of the process for material was:

Coal, 145 tons at $5.25	$ 761.25
Perchloride of iron, 300 carboys of 140 lbs. at $0.0275	1,155.00
Lime, 2,240 bbls. at 1.40	3,136.00
Vitriol, 40 carboys of 140 lbs. at $0.0275	154.00
	$5,206.25

or $16.78 per million gallons treated.

Brooklyn, N. Y.[1]—The Borough of Brooklyn, New York, maintains 4 chemical precipitation plants, employing the process patented by J. J. Powers. Two of these are at Coney Island, one near Sheepshead Bay, and the third and largest at East New York. Being similar in principle, the latter, only, will be described.

The sewage, amounting in 1907 to about 12 million gallons per day from a population of about 100,000 persons, including the surface drainage from 3200 acres, is first dosed with lime to the amount of 5 bbls. per million gallons and then enters, in parallel, two sedimentation channels 16 ft. wide × 7 ft. deep × 350 ft. long. From these it passes to a well 40 ft. in diameter from which it is pumped to an outfall flume.

For from 36 to 48 hours before cleaning out the tanks the sludge is disinfected with chlorine generated from 108 lbs. sulphuric acid, 64 lbs. common salt and 48 lbs. manganese dioxide. The sludge is then pumped on to shallow lagoons excavated near the plant and dried.

[1] Rep. Metropolitan Sewerage Com. of N. Y., 1910, p. 259.

TABLE XXVII

RESULTS OF ANALYSES OF SEWAGE MADE DEC. 11, 1907, AT EAST NEW YORK DISPOSAL PLANT BY DR. D. D. JACKSON. PARTS PER MILLION

	Raw			Effluent		
	Dissolved	Suspended	Total	Dissolved	Suspended	Total
Total solids	441	136	577	454	134	588
Loss on ignition	176	115	291	110	98	208
Fixed solids	265	21	286	344	36	380
Fats and fatty acids			397			234

At the four above-mentioned plants there were said to be produced in 1907 33 1/3 cu. yds. of sludge per million gallons of sewage.

There were used for precipitation 1.15 bbls., or 263 lbs. of lime and 133 lbs. of perchloride of iron per million gallons of sewage, and for disinfection of sludge there were used:

	Lbs. per million gallons sewage	Lbs. per cubic yard sludge
Sulphuric acid	2.8	.084
Salt	1.6	.048
Oxide of manganese	1.2	.036

Regarding the efficacy of these plants, Dr. D. D. Jackson states:

"The process of purification has not materially reduced either the suspended matters or matters in solution. * * * * * The effluent is * * putrescible at the end of 24 hours."

VIII. THE DISPOSAL AND UTILIZATION OF SLUDGE

1. *Disposal of Night Soil on Farms*

The most primitive as well as a most effective method of utilizing sludge is by its direct application to the land as a

fertilizer. By the removal of fecal matter from cesspools before it has been diluted with any large volume of water, the processes of sedimentation and separation are avoided, although for other reasons the use of cesspools is not to be advocated. This method of disposal has been employed up to the present time on such a large scale in Baltimore, Md., that a brief description is given here.

A contract is entered into with the city by which the right is secured to charge the householder a certain sum for the removal of night soil. This is drawn by suction with "odorless excavators" from the cesspool when it becomes necessary, and conveyed to barges holding 450 loads of six barrels (about 200 gallons net) each, for which the contractor operating the barges receives 25 cts. per load for disposal. In 1909, according to Dr. James Bosley, Commissioner of Health, 61,748 loads were removed in this way, in addition to which more or less finds its way, illegally, by other channels to farming land in neighboring counties.[1] The barges are towed down the Patapsco River, chiefly to Bear Creek, about 8 miles distant, where their contents are pumped by specially designed pumps of large capacity to lagoons prepared for its reception by the farmers. An ordinary lagoon or pit holds a scow load, or about 100,000 gallons, and the operation of pumping occupies about two hours. For this amount, which is delivered to him as required, the farmer paid the contractor several years ago $1.67 per thousand gallons. The heavy sludge remaining in the scow is removed by shoveling into carts and is also taken by the farmer.

The pits are used merely for storage until the material is required, when it is bailed with long-handled dippers into tank carts and sprinkled over the fields.

A large variety of crops is fertilized in this way. One farmer stated that he had used 6 barge loads of night soil (at the rate of 4000 gallons per acre) and 35 barge loads of garbage (also handled in this way) during the year on 150 acres of kale, cabbage, tomatoes, potatoes and spinach. The liquid portion appeared to be more immediately effective, but the heavier portion produced a more lasting effect.

The odors in the vicinity of these lagoons are very offensive, but, so far as known, they have not had an unfavorable effect on the health of those living on the farms. The nuisance from

[1] Also, about 2030 houses are connected (1911) with storm water drains. Dr. J. M. Bosley.

flies has been considerable and the possibility of conveying disease by them should not be forgotten.

A more serious objection lies in the illegal use of night soil on growing vegetables before gathering for the market. This is very difficult to prevent on account of the inaccessible location of the farms. Application to the crops is supposed to be made several weeks (10 in the case of kale) before gathering.

With the introduction of sewers this system of disposal and utilization will, of course, be abandoned.

2. *Dumping at Sea*

Disposal of sludge by dumping at sea, as practised at London, Glasgow, Dublin, Manchester and Salford, is almost unknown in the United States. The cost at several of these places is as follows:

TABLE XXVIII

Cost of Transporting Sludge to Sea. Adapted from Report V, Royal Commission on Sewage Disposal

Place	Years	Average tons of sludge per annum[1]	Average per cent. moisture in sludge	Total cost in cents of sea disposal incl. int. and sinking fund per ton of sludge[1]	Cents per ton of dry solid matter[1]	Cents per ton of sludge 90 per cent. water[1]	Remarks
Glasgow	1906–7	341,600	86.8	9.7	74.0	7.42±	60 year loan.
Salford	1902–6	152,320	79.0	17.1	81.5	8.15±	Heavy canal dues.
Dublin	1906–7	128,307	90.0±	9.0	90.9	9.09±	No harbor dues, short distance.
London	1903–6	2,838,080	92.0	8.2	103.0	10.30±	
Manchester	1903–4–5–7	188,720	86.0±	17.4	124.7	12.47±	Heavy canal dues.
Southampton	1906–7	15,624	90.0±	30.5	305.9	30.59	By contract.

Further details are given in the following table:[2]

[1] Tons referred to are of 2000 pounds.
[2] Fifth Rep. Royal Com. on Sew. Disp., p. 167.

TABLE XXIX

Works	For year	Per cent. moisture	Cost per ton			Cost per million gallon		
			Land charges	Sea charges	Total	Land charges	Sea charges	Total
London:								
Barking	1907	92.04	$0.050	$0.067	$0.117	$1.57	$2.10	$3.67
Crossness	1907	91.65	0.046	0.067	0.113	0.78	1.13	2.91
Glasgow:								
Dalmuir	1907–8	86.69	0.016	0.049	0.065	0.34	1.06	1.40
Manchester	1906–7	....	0.044	0.117	0.161			

The first three sludges are from chemical precipitation and the last from septic tank treatment.

Recently Providence has disposed of its sludge cake by dumping it in Narragansett Bay from a scow 135 ft. long×38 ft. wide ×11 ft. deep. This is divided into 6 compartments and has a capacity of 850 cu. yds. when filled level, and 1050 cu. yds. when heaped. This is towed about 10 miles down the bay and deposited in a depth of about 65 ft. of water.

As already mentioned, the sludge removed from the deposit sewer of the Boston Main Drainage is taken by a scow out into Massachusetts Bay and dumped in deep water.

Disposal of sludge by dilution is also practised at Columbus, Ohio, where it is stored until the river water is in freshet or of sufficient volume to render its discharge unobjectionable. This was also tried with the sludge from the experimental tanks at Waterbury, Conn., where it was observed that when diluted by 1650 volumes of water in the Naugatuck River, there were no apparent odors resulting and the mixture was non-putrescible.

3. *Application to the Land*

Direct application to the land is frequently employed at small works. The ordinary cost of this is given by Mr. W. B. Ruggles as from 40 to 50 cts. per ton of the solid content and the area required is from 1 to 2 acres (2 or 3 in. deep) per 1000 tons of sludge.[1] Where trenching and burying is used, the cost is about 9 to 14 cts. per ton of wet sludge, or from 90 cts. to $1.40 per ton

[1] Kinnicutt, Winslow and Pratt.

of solids, exclusive of the cost of land. The area required is from 1/4 to 1/2 acre per 1000 inhabitants,[1] or from 0.2 to 0.4 acres per 1000 tons of sludge.

At Mansfield, Ohio, the total cost of disposing of 1200 cu. yds. of septic sludge on the land, employing 6 men and a horse at a cost of $15 per day, was about 50 cts. per cubic yard. About 40 cu. yds. were handled per day of 8 hours. No nuisance is experienced except during the operation of emptying the tanks, when there is a noticeable odor.

At White Plains, N. Y., the sludge from chemical precipitation is pumped once a week on to land to a depth of 3 in. In about 7 days it dries sufficiently to be winrowed and is later wheeled to a dump. About 5 cu. yds. were produced from a population of 14,000. Two sludge beds of 1800 sq. ft. each were used alternately.

Drying in lagoons is practised in Reading, Pa., the area required being about 1/4 acre for the 4280 cu. yds. of wet sludge produced in 1910. No offensive conditions were noted during the year.

Experiments were conducted at the Philadelphia testing station with drying in 4 lagoons 8 ft. × 12 ft. in size.

With sludge derived from plain sedimentation, the results were as follows:

TABLE XXX

RESULTS OF DRYING SLUDGE IN LAGOONS. PHILADELPHIA

	Time in days	Depth in inches	Per cent. moisture	Rainfall, inches	Cubic yards sludge per acre
Screened.....	0	12.20	82.8	0	1600
Screened.....	26	7.67	57.0	0	1000
Screened.....	49	3.50	51.6	0.43	470
Screened.....	0	13.50	90.1	0	1800
Screened.....	62	7.00	61.0	3.14	950
Crude.......	0	12.00	88.7	0	1600
Crude.......	59	4.70	62.8	2.59	640

In general, wet sludge 12 in. deep dries to about 60 per cent. moisture in 6 weeks, leaving about 0.4 of the original volume to be removed from the bed or lagoon.

[1] *Eng. Rec.*, Vol. LXIII, p. 79.

Sludge from the Emscher tank dried rapidly and soon became odorless. It was run onto a bed under cover consisting of:

Fine sand	6 in. at the top.	
Gravel	6 in.	
Sand	2 in.	Foundation resembling natural conditions.
Gravel	6 in.	
Broken concrete	24 in.	

This was underdrained by 3-in. perforated tiles.

It was found that 12 in. of sludge placed on this bed in winter was in condition to be removed in 12 days, although containing 68 per cent. moisture.

The average time for drying in the Emscher District, according to Mr. Charles Saville,[1] is about 7 days, but in summer it is sometimes removed after but 2 days, the moisture in the dried sludge varying from 55 to 65 per cent.

Experiments were made in lining the lagoons with various materials: coarse sand, fine sand, rice coal and sawdust. Coal and sawdust were favorable to subsequent incineration while sand was liable to form clinker. "The thick layer of sawdust was more efficient than the thin, whereas the thick layer of coal was less efficient than the thin, and the thick layer of sawdust was equally efficient to the thin layer of coal." About the same amount of moisture was removed by sand and sawdust, this being about 75 per cent.

At the Elmhurst (Borough of Queens, New York) plant the supernatant water is drawn from the tank at mid-depth. The sludge with the remaining roily liquid is then placed on a sludge filter 20 ft.×50 ft. in area and 3 ft. 3 in. deep. The filter is under cover. It is made of graded material varying in size from 3 in. at the bottom to sand, with 4 in. of combustible material—usually buckwheat coal—at the top. The bed is underlain by a system of 2 1/2-inch steam pipes to facilitate drying.

The heavy liquid is delivered to the surface of the bed by a 12-in. pipe and a trough. The filtrate passes by underdrains to a pump well and the de-watered sludge is scraped, with the coal, from the surface after about 3 days' drying, and burned under boilers.[2]

Tests made at the Chicago experimental plant showed that sludge from plain sedimentation containing 90 per cent. moisture

[1] Ass't Eng'r Emscher Association, *Eng. News*, Vol. LXV, p. 664.

[2] *Eng. Rec.*, Vol. LII, p. 87.

dried out to a thickness of 4 in. with but 50 per cent. moisture in 30 days during warm weather.

At Brockton, Mass.,[1] the dried sludge raked from the intermittent filters was first burned on wood fires. As this caused a nuisance, it was then (1890) sold to farmers for $125, and later (1901 to 1906) for $150 per annum. Since 1909 it has been given away so as to secure a prompt removal. In 1908 the sludge averaged 136,000 gallons per day and contained 11,177.5 parts per million of total solids. It produced about 3500 tons of dry sludge. The rakings were of the following composition:

Moisture	16.22 per cent.
Phosphoric acid	.78 per cent.
Potassium oxide	.51 per cent.
Nitrogen	1.45 per cent.
Calcium oxide	.30 per cent.
Insoluble matter, sand, etc	70.13 per cent.

This is used as a fertilizer on corn, potatoes, millet and other grasses, but, with the exception of corn, additional potash and phosphoric acid are required.

In general, the cost of raking and removing the sludge from intermittent sand filters in Massachusetts amounts to about $3 per million gallons of the sewage applied, or from 12 to 30 cts. per capita of population.

In the arid portion of the west, conditions are more often favorable to the direct application of the raw sewage to the land. According to Dr. W. F. Snow, Secretary of the State Board of Health of California, some towns in that state operating sewage farms realize from $500 to $5000 a year in the crops of hay, walnuts, potatoes, alfalfa and eucalyptus wood produced.

According to Dr. Voelcker,[2] the yield of corn (wheat, etc.) is increased from 10 to 12 per cent. by the application of sewage sludge to the extent of 40 lbs. of nitrogen to the acre, while artificial fertilizers of equivalent strength increase the yield from 16 to 17 per cent. The use of sludge increases, in particular, the stem of the plant and therefore the straw produced, but in any case its value depends even more on the amount of moisture and the lime contained than upon the percentage of nitrogen. He concludes that from a practical point of view none of the sewage

[1] *Eng. News*, Vol. LXII, p. 251.
[2] Fifth Rep. Royal Com. on Sew. Disp., p. 187.

sludges used would be worth 10s. ($2.50) a ton on the farm for wheat-growing purposes.

The economical use of sludge as a fertilizer being exceptional, its disposal on land is reduced to either merely drying or burying. As to the choice of these, Mr. George W. Fuller states:[1]

1. That sludge drying beds are usually unsatisfactory for large plants and that when they have been used with a moderate degree of success this has usually been during cool weather.

2. That the burial of sludge in trenches has merit in the case of small installations, but that in the case of large plants this cannot compete with the employment of the Emscher tank, the product from which is inoffensive and is therefore easily disposed of.

4. *Filter-pressing*

Pressing sludge is usually confined to plants employing chemical precipitation and where, therefore, there are large volumes of a rather watery product to be handled.

At Worcester this process cost, in the year ending November 30, 1910:

Per million gallons of sewage,	$2.76
Per thousand gallons of sludge,	$1.20
Per ton of solids,	$3.50

The cake is used for filling in land.

At Providence the total cost of sludge disposal in 1909 was $4.22 and in 1910 $4.06 per million gallons of sewage, and the cost of sludge pressing was $2.85 and $2.62, respectively, per ton of dry solids.

Aside from the Worcester and Providence plants, where the cost data are carefully kept, the information to be had from American practice is so meager that the following supplementary figures referring to sludge pressing in England are given.

In Leeds, according to W. W. Ruggles,[2] the cost of pressing was, in 1910, but $14,784.61 for 16,017 tons of dry solids, or about 92 cts. per ton.

[1] Sewage Disposal with respect to Offensive Odors. M. I T. Congress of Technology, April, 1911.

[2] Exclusive of sewage beds and filters. Sewage Sludge Disposal, *Eng. Rec.*, Vol. LXIII, p. 79.

Mr. Ruggles gives the cost of cremating sludge cake as about $3 per ton of dry material, and that of carting and dumping the cake as seldom less than 60 cts. per ton and frequently two or three times that amount, depending on the haul.

According to the Royal Commission on Sewage Disposal,[1] the cost of pressing sludge under ordinary conditions, reducing the moisture, 90 to 95 per cent. in the raw sludge, to about 55 per cent. in the pressed cake, may be taken as follows:

TABLE XXXI

COST OF PRESSING SLUDGE INCLUDING INTEREST AND SINKING FUND

	Wet sludge per ton	Pressed cake per ton
For populations of 30,000 or more and ordinary sewage.	13.2 cts. to 15.6 cts.	59.7 cts. to 70.6 cts.
For populations less than 30,000 and where, on account of septic or greasy sludge, 5 to 20 per cent. lime had to be added.	18.1 cts. to 28.0 cts.	81.4 cts. to $1.249

According to Santo Crimp, if the moisture is reduced by pressing to 50 per cent., the product from each inhabitant will equal 2 cwt., or 0.112 ton, per annum after efficient chemical precipitation.

Pressed sludge cake weighs, according to Rideal, 8 2/3 tons per million gallons of sewage, and the moisture can be reduced from 50 per cent. to 12 per cent. by air drying.

The value of this air-dried sludge he estimates for different English plants as follows:

From $2.48 (Birmingham using lime, and Windsor employing the Hilles process) to $5.90 (Coventry using sulphate of alumina) per ton of 2000 lbs. The dried sludge at Aylesbury, where the A B C process is employed, is valued at $7.10 per ton.

5. *Drying with Centrifugal Machines*

Drying by centrifugal machines has hardly been attempted in the United States. While admitting the excellent results obtained by the Schaefer-ter Meer machine abroad, its high first cost has prevented its introduction into this country up to the present time.

[1] Fifth Rep. Royal Com. on Sew. Disp., p. 170.

A centrifugal dryer of more simple construction is used at Reading, Pa., however, for de-watering the material received from the rotary screen. The sludge is delivered with 89.5 per cent. moisture by a screw conveyer to canvas bags. These are placed by hand in the hydro-extractor, which is about 6 ft. in diameter and 3 1/2 ft. high. On removal the moisture has been reduced from 89.5 to 73 per cent., 19.6 per cent. of the product being volatile, and the weight has been reduced from 62–70 to 31–35 lbs. per cubic foot. The material taken from the machine is burned under the boilers of the sewage pumping station.

The manual labor required in the operation is a serious objection to this type of dryer in connection with large plants.

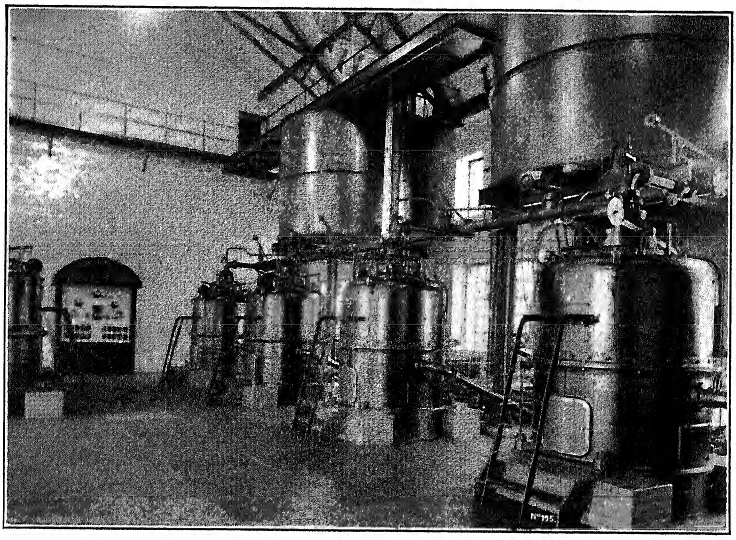

FIG. 41.—Centrifugal sludge-drying machine at Frankfort, Germany. (Courtesy of The Lathbury-d'Olier Co., Philadelphia.)

In Bradford, England, the cake from sludge presses is heated in a rotary drier, which reduces the moisture from 33 to about 9 per cent., leaving the dried product in a form suitable for shipping. This is said to find a ready market at $2.17 per ton and has proved so profitable that similar machines are to be installed at the sewage treatment plant at Dublin.

The cost of producing the dried product for use as a filler for

fertilizers under American conditions is estimated by Mr Ruggles as follows:

	Cost per ton
Filter pressing	$1 00
Drying	35
Grinding	16
Bagging	15
Total	$1 66

While its value as a fertilizer, which has been separately estimated at $6.76 and $10.79 per ton, is assumed to be at least $4, leaving a profit of $2.34 per ton.[1] The cost per cu. yd. of dried sludge at Hanover has been estimated at 36 cents and in America would probably be more than double this amount.[2]

Kinnicutt, Winslow and Pratt give the probable cost of drying by centrifugal machines as from 5 to 7 cents per cu. yd. of wet sludge.

With regard to the Schaefer-ter Meer machines, the following data are from the operation of the 4 units installed at Hanover:

Dried material produced per unit per day	26–39 cu. yds.
Dried material produced per million gallons sewage	3.3–4.9 cu. yds.
Cost of operation:	
Per unit per day	$12.85
Per capita per annum	.02
Per million gallons sewage	1.62
Per cubic yard wet sludge	.07–.10
Per cubic yard dried sludge	.33–.50

6. *Recovery of Calorific Value*

No attempt has been made to utilize the latent calorific value of sludge on a large scale in the United States, but some experiments have been made in this direction by the Massachusetts

[1] Estimate made by a "well-known laboratory in New York"

Ammonia, 2.6 per cent	$6.52
Equivalent of bone phosphate, .66 per cent	.07
Potash, .24 per cent	.17
	$6.76

Estimate on sample furnished *The American Fertilizer* of Philadelphia.

Nitrogen, 52.2 lbs. at 20 cts	$10.44
Phosphoric acid, 2.2 lbs. at 4 cts	.09
Potash, 6.2 lbs. at 4.25 cts	.26
	$10.79

[2] Rep. Sew. Disp. Chicago. Geo. M. Wisner, 1911.

State Board of Health,[1] by the city of Worcester, Mass.,[2] and by the City of Philadelphia.[3]

In 1898 the Massachusetts State Board of Health demonstrated that gas was evolved from the sludge rather than from the soluble contents of sewage.

In the year 1900 the following volumes of gas were produced in a septic tank, illustrating clearly the effect of temperature.

TABLE XXXII

GAS PRODUCED IN SEPTIC TANK

	April 21 to May 1	May 2 to May 22	July 10 to July 20	Oct. 4 to Oct. 6
Average hours storage	28	21	28	23
Average temperature in tank	51	52	74	65
Cubic feet gas per 1,000,000 gallons of sewage passed.	6100	8400	11300	6000
Cubic feet gas per 1000 gallons of tank capacity.	5.3	9.5	9.5	5.3
Cubic feet gas per cubic foot sludge in tank	0.71	1.27	1.27	0.71

To illustrate the effect of varying composition, the amount of gas obtained from the fermentation of different sludges was determined.

TABLE XXXIII

AMOUNT OF GAS PRODUCED BY FERMENTATION OF DIFFERENT SLUDGES

Source	Days	Per cent. organic matter in sludge	Centimeters of gas formed per gram of	
			Sludge	Organic matter
Tannery sewage	61	51	0.00	0.00
Lawrence sewage	26	84	0.34	0.40
Lawrence sewage	21	78	5.80	7.45
Septic tank	30	46	4.14	9.00

Septic tank gas was found to be composed principally of methane, carbon dioxide and nitrogen. The methane varied from 28.7 to 79.0 per cent. When obtained from the fermenta-

[1] Rep. Mass. St. Bd. Hlth., 1908, p. 492, *et seq.*
[2] *Eng. News*, 1892.
[3] Rep. Bureau of Surveys, comprising work at the sewage experiment station at Spring Garden, Philadelphia, 1910, p. 191, *et seq.*

tion of sludge, the methane varied from 79 per cent. in the case of septic sludge to 2 per cent. in the case of ordinary sewage sludge.

TABLE XXXIV

COMPOSITION OF GAS PRODUCED

Source	Per cent		
	CO_2	CH_4	N
Septic tank A	3.4	79.0	16.0
Septic tank B	42.2	37.5	19.0
Andover septic tank .	9.8	28.7	61.0
Sludge from regular sewage	28.7	1.8	69.5
Sludge from septic tank	11.7	75.9	12.4

Experiments were begun in 1908 on the distillation of gas from sludges of different kinds. The average volumes produced were as follows:

TABLE XXXV

GAS PRODUCED PER TON OF DRY SLUDGE

From settled sewage sludge	6600 cu. ft.
From chemically precipitated sewage sludge	8100 cu. ft.
From septic sludge	4900 cu. ft.
From peat	8400 cu. ft.
From soft coal	8600 cu. ft. to 12,900 cu. ft.

While the composition of the gases depended much on the source of the material, those from sludge contained, in general, more CO_2 and CO and of "the so-called illuminants" than those derived from coal, while the H and CH_4 were less in quantity. The resulting coke amounted to from 45 to 65 per cent. of the weight of the dry sludge and, although containing much mineral matter, could no doubt be burned as fuel. Analyses of this showed from 1.1 to 1.7 per cent. of available P_2O_5 and about 22 per cent. of the nitrogen in the sludge. "Much of the fats * * * * distilled over with the tars. * * * This by-product could readily be disposed of by mixing it with the coke

and burning, or if it were formed in sufficient amounts it could be burned directly, in the same manner as water gas tars are utilized."

TABLE XXXVI

ANALYSES OF SLUDGES USED, PER CENT. OF COKE FORMED AND AMOUNT OF NITROGEN IN COKE

Source	Composition of sample before distillation per cent.			Per cent. coke produced	Per cent. N (by wt. of total sludge)		Per available P_2O_5 in coke
	Total N	Loss on ignition	Fats		Found in coke	As NH_3 in washer	
Lawrence (settled sewage)	3.36	36.8	12.8	63.5	.11	.586	1.33
Andover (settled sewage)..	2.14	46.6	27.5	59.5	.67	.226	1.33
Clinton (settled sewage).	2.36	74.4	7.7	44.5	.72	.404	1.44
Brockton (settled sewage)	1.76	46.6	6.2	60.5	.94	.137	1.17
Worcester (chem. precip.)	1.19	44.5	3.2	54.0	.09	.544	1.67
Septic tank	2.46	47.9	8.3	68.5	.27	.497	1.15
Peat	2.54	92.0	......	49.0	.70	.700	0.31
Soft coal (aver. of 4 kinds steam and gas coal).	...	96.8	......	77.3	....	.222	....

TABLE XXXVII

GASES PRODUCED BY DESTRUCTIVE DISTILLATION OF SEWAGE SLUDGE

Source	Cu. ft. gas per ton of sample	CO_2 %	Illuminants %	O %	CO %	H %	CH_4 %	N %
Lawrence (settled sewage)..	4900	4.4	2.2	0.3	30.7	34.9	18.6	9.1
Andover (settled sewage)..	6400	7.4	15.1	0.6	14.3	22.9	34.3	5.4
Clinton (settled sewage)......	9100	8.3	6.7	0.0	20.4	33.2	24.5	7.0
Brockton (settled sewage).....	6000	16.5	21.4	0.2	10.3	22.6	29.1	0.2
Worcester (chem precip.)..	8100	14.2	4.9	0.3	29.8	32.6	16.2	2.2
Septic tank..................	4900	7.5	1.0	0.1	24.3	44.0	13.0	10.2
Peat....................	8400	39.0	4.7	0.2	11.0	28.0	17.1	0.0
Soft coal..................	10200	1.6	2.0	0.1	5.2	62.3	25.7	3.2
Illuminating gas (Lawerence).....	..	3 4	9.1	0.0	21.5	42.5	19.7	3.8

The Worcester experiments referred to were made in 1891 and consisted in burning 45 tons of sludge containing 46 per cent. moisture with the aid of 3 cords of wood. The total cost of its disposal, including the manual labor of collecting the sludge from the beds and conveying it to the furnace, was $3 per ton of dry sludge.

At the Philadelphia sewage experiment station wet sludge was mixed with an equal weight of rice-size anthracite coal. The resulting mixture was 1.57 times the volume of the sludge and its specific gravity 1.29. The percentage of moisture was reduced in this way from 91 per cent. to 48 1/2 per cent. After placing in a sludge lagoon to a depth of 12 in. and drying 24 hours, this was reduced to about 27 1/2 per cent., and in 9 days to 22 1/2 per cent., the temperature being about 37° F.

The result of the mixing is shown in the followng table:

Constituents	Per cent.	Lbs. per cu. yd.
Moisture	45.5	1,069
Coal	50	1,175
Dry residue of the sludge	4.5	106
	100.	2,350

Each cubic yard of wet sludge, after drying, with 1760 lbs. of coal, produced one ton of the dried mixture delivered at the boiler house for fuel.

The British thermal units contained in the materials used were:

In the coal as received	12065
In the sludge as burned	1216 to 2165

TABLE XXXVIII

Results of Burning Air-dried Sludge With Coal

Weight of sludge broken to 2-in. size, per cu. yd. in lbs.	710	to	1015
Percentage of water in sludge	15.3	to	40.2
Percentage of dry residue, volatile	24.5	to	30
Lbs. dry residue in sludge used	168	to	233
Lbs. volatile matter in sludge used	48	to	70
Lbs. coal burned with sludge	192	to	285
Lbs. wet sludge burned per minute	2.66	to	4.15
Lbs. volatile matter burned per minute	.555	to	.705
Lbs. dry residue burned per minute	2.18	to	2.47
Lbs. of coal burned per pound of			
Wet sludge	.68	to	.895
Dry residue	.817	to	.945
Volatile matter	.233	to	.25

The experiment demonstrated that it was possible to burn sludge in this way under boilers, but the degree of economy effected was not determined.

Samples were then taken of air-dried screened sewage sludge, crude sewage sludge and Emscher tank sludge and mixed with equal weights of pea coal, and of wet sludge mixed with equal weights of rice coal, but the moisture to be evaporated interfered with realizing their full caloric value. The small coal consumption it was believed, however, would frequently justify the employment of this process in connection with sludge disposal.

TABLE XXXIX

RESULTS OF TESTS OF FUEL VALUE FOR STEAM PRODUCTION OF MIXTURE OF SLUDGE AND COAL

	Per cent. wet sludge in mixture	Fuel prior to burning		Lbs. water evap. per lb. fuel	Eqivalent evaporation from and at 212° F. per lb. of fuel
		Moisture	b.t.u.		
Rice coal and wet sludge.	12.4 22.9	2.75–3.87	10700–11252	4.20–4.50	4.60–4.92
Pea coal and dry sludge.	50	1.15–2.03	8832–8875	2.67–3.32	2.92–3.63

CHAPTER IX

Summary and Conclusions

In selecting the best method for removing the solid matter suspended in sewage we must consider the kind of subsequent treatment, if any, it is to receive. If the effluent is to be put through sprinkling filters or contact beds or if it is to be applied to the land it should be delivered in as fresh a condition as possible and the coarser particles should be removed by screens, scum boards, grit chambers or a combination of some such devices. Otherwise the process will be more offensive and the filter beds more likely to clog. If it is to be discharged into a stream, too coarse material should be removed as causing deposits on the bottom or an offensive appearance of the surface of the water. If, however, it is to be utilized on account of its calorific or fertilizing properties the sludge from plain sedimentation or Dortmund tanks or that from fine screens is preferable to the more completely mineralized product from septic or Emscher tanks. If septic tanks are employed the grit need not ordinarily be first intercepted, but may be handled in connection with the other sludge, but in the case of Emscher or Dortmund tanks the grit is undesirable, as tending to clog the discharge pipe. Chemical precipitation is sometimes to be preferred in the case of a very strong sewage or one containing acid wastes in large quantity, or in case it is thought best to press the sludge into cake. If the sludge is to be buried, air dried, used for filling in land or dumped at sea the septic and Emscher tanks have the advantage of furnishing a product of small volume which may be readily handled with the minimum offense. Fine screening requires but little room and therefore should be considered where land values are high, but in this case, as well as in plain sedimentation, the resulting detritus or sludge contains so large an amount of moist organic matter that its prolonged storage is objectionable in populous districts. These questions have been so fully treated by Dr. Elsner in Part I that it is unnecessary to dwell further on them here.

Having decided on the general method to be employed the results that may be expected, based on experience in the United States, are about as follows:

TABLE XL

REMOVAL OF SUSPENDED SOLIDS BY DIFFERENT METHODS OF TREATMENT

Method	Per cent. removed	Cu. yds. sludge per mil. gal. sew.	Per cent. moisture
Bar screens, spaces 3/4 in. to 1 in.	2 to 10	0.1 to 0.25	65 to 75
Mesh screens, spaces 1/4 in. or less	15 to 25	0.6 to 1.4	80 to 90
Grit chambers	5 to 10	0.1 to 0.8	35 to 50
Plain sedimentation	50 to 70	4 to 7	87 to 93
Septic tanks	50 to 70	1.5 to 3	80 to 90
Emscher tanks	50 to 70	1 to 2	75 to 85
Chemical precipitation	75 to 90	20 to 25	86 to 92

These figures are subject to so great a variation, depending on local conditions, that they are merely given as a guide to indicate the limiting values under ordinary conditions.

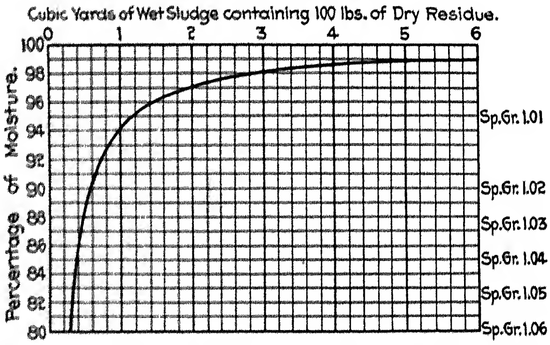

FIG. 42.—Volumes of sludge with varying percentages of moisture. (Reproduced from Report on Disposal of Sewage, Philadelphia, 1911.)

The sludge produced has generally been given heretofore in cubic yards. In England it is more customary to mention the product by weight and as this is also frequently done in the United States the following equivalents may be found useful, although these are subject to variation, depending on the character of the ingredients and the space occupied by air after draining.

TABLE XLI

APPROXIMATE WEIGHT OF A CUBIC YARD OF SLUDGE

Per cent. moisture	Pounds	Tons
100	1685	0.84
95	1695 to 1705	0.85
90	1720 to 1775	0.86 to 0.88
85	1750 to 1820	0.87 to 0.91
80	1790 to 1865	0.89 to 0.93

In selecting the method of treatment the cost is an important, and sometimes the controlling, factor. The septic tanks at Washington, Pa., cost $4173 per million gallons treated daily or $15,650 per million gallons gross capacity,[1] while the corresponding costs for the larger Columbus, O., tanks (the contract price for which was particularly favorable) were $3340 and $8320, respectively. Rectangular Emscher tanks with 3 hours' retention of sewage and 5 months' retention of sludge would probably cost from $5000 to $7000 per million gallons daily flow or from $30,000 to $40,000 per million gallons gross capacity, depending on the excavation. The following figures on a per capita basis are given by Mr. George M. Wisner, Chief Engineer of the Chicago Sanitary District.[2]

TABLE XLII

COMPARATIVE COST OF SETTLING TANKS BASED ON A SEWAGE FLOW OF 200 GALLONS PER CAPITA DAILY

Type	City	Nominal period of settling	Cost per capita for construction
Straight-flow	Columbus O.	6 hours	$0.58
Straight-flow	Columbus O.	8 hours	$0.77
Dortmund tank	Gloversville N. Y.	4 hours[3]	$0.84
Emscher tank	Atlanta Ga	3 hours[3]	$1.44

In case the area available for sludge drying is limited or costly the Emscher tank has a decided advantage, as fully explained

[1] According to Mr. D. M. Belcher, Assoc. M. Am. Soc. C. E.
[2] *Eng. Rec.*, Nov 4, 1911.
[3] Sludge storage not considered.

by Spillner and Blunk. As a result of the Chicago Experiments Mr. Pearse is of the opinion that with 6 to 8 hours' retention of sewage in a septic tank the sludge requires at least 20 days to become spadable, whereas with but from 1 to 3 hours' retention of sewage in an Emscher tank the sludge is in condition to be handled in about 5 days, requiring, therefore, not more than one-fourth the area. For plain settled sludge a still larger area is required amounting to from 1 to 2 acres per 1000 tons if air dried, or from 0.2 to 0.4 acres per 1000 tons if buried. See page 239.

It is concluded that the land required for Emscher tanks amounts to 0.63 sq. ft. per capita or, with appurtenances, 10 sq. ft. per capita; and that for the drying beds there should be provided 0.3 sq. ft. per capita or, including tracks, dikes and distribution, 0.5 sq. ft. per capita. The cost of the beds is estimated at 15 cents per capita.[1]

Experience in the Emscher District has indicated[2] that three-fourths acre of land is required for every 10,000 persons, producing about 30 cu. yds. of spadable sludge (less than 10 per cent. of the volume of the fresh sludge) per annum. One man can handle the sludge from three times the above population if the point of deposit is near the plant.

As to the final disposition of the sludge the method selected depends, aside from the cost of land, on the character of the sludge, the material available for sludge beds, the proximity of dwellings and the general character of the actual and prospective development in the neighborhood.

In general terms, perhaps the following selection, as proposed by Kinnicutt, Winslow and Pratt, is as appropriate as can be given without going into greater detail:

1. In the case of small isolated plants air-drying on the land or in lagoons is generally preferable, giving the dried sludge to farmers or burying it in the ground.

2. For larger, but moderate-sized plants, burying in trenches is found satisfactory.

3. For large cities located on the coast the cheapest and most expeditious method is removal by scow or steamer and dumping at sea.

4. For large inland cities mechanical drying is often necessary,

[1] "Rep. on Sewage Disposal." George M. Wisner, Chicago, 1911.
[2] Charles Saville, *Jour. Assoc. Eng. Soc.*, July, 1911.

in which case the product can be given away as a fertilizer or it can be buried or, in isolated localities, used for filling in land. If these methods of disposal are not feasible for any reason the product can be mixed with house refuse or with a small amount of coal and burned in a destructor.

At the present time there are over 330 municipal sewage treatment plants in the United States. Of these, about three-fifths employ the septic tank, either for the complete, or as preliminary process and one-fifth employ plain sedimentation. The former method, which might more properly be called the *semi-septic* process, has been very generally adopted in the middle west during the past 10 years. Although the term *septic* has been popularly attached to these tanks they are not true septic tanks in the light of the Saratoga decision. Their effluents often contain dissolved oxygen and aerobic conditions undoubtedly often exist in those parts of the tank through which the clearer liquid passes, while the solids, detained by efficient baffling and generally collecting largely in the scum by reason of the entrained gas, may at the same time develop septic or anaerobic conditions.

The period of retention is generally comparatively brief—often not over 4 hours—so that the sewage does not become thoroughly putrefactive or devoid of dissolved oxygen before passing off. These tanks and those devised by Travis and Imhoff are similar in this respect and differ from the septic tank of Cameron, where the sewage is retained at least 12, and oftener 24 hours. This, too, is the usual practice in operation in the Eastern states. The divergent results obtained in the former tanks, for which the term "hydrolytic" has been used, from those obtained with the true septic tank has resulted in a certain confusion of ideas in regard to the efficacy and offensiveness of the septic tank process. The shorter period of retention, combined with a sewage both fresh and weak, results in an almost entire freedom from offensive odors in many of the western plants that is usually not enjoyed where a strong sewage is retained for an entire day in an uncovered tank. So, too, there appears to be a marked difference in the amount of sludge and scum produced; for, as noted by Mr. J. W. Alvord, the deposits, requiring removal from the western plants handling domestic sewage only are frequently very small in amount, while the scum forms rapidly, after septic action is established, to a very considerable thickness.

This suggests the desirability of studies to determine the best

way of removing and disposing of the scum, which differs materially in character from ordinary sludge.

Although in the Emscher District the scum does not seem to accumulate to a great thickness it may cause trouble in Emscher tanks through its buoyancy by clogging or overtapping the vent openings unless these are of ample width. By breaking up the scum occasionally with a rake much of it will sink as a deposit with the sludge and release any accumulation of contained gas.

When removed from the surface of a tank receiving fresh sewage and whose contents are not thoroughly septic this scum is not particularly offensive and may often be dried out on beds in the open air before final disposal if not in the immediate vicinity of dwellings.

The absence of sulphuretted hydrogen, and objectionable odors generally, in the tanks of the Emscher Association, has been received with a certain amount of incredulity. There appears, with our present knowledge, no good reason why these gases should not form in one style of tank as well as another, provided the other conditions are similar. Possibly the motion of the sludge particles caused by the eruption of gas bubbles and the settlement and withdrawal of sludge may influence the formation of these gases, but it would seem to be largely accounted for by the fact that the greater part of the organic matter from which sulphuretted hydrogen is produced remains in suspension or in solution in the sedimentation chamber and passes out with the effluent, while in the true septic tank these are retained in the tank until putrefaction is energetic and the odors, which are chiefly derived from the non-sedimentable portion rather than from the sludge, are given off in large amounts.

With regard to sludge disposal in America, while there are isolated examples of lagooning, drying on the land, centrifuging, pressing and burning, these are so few in number, or else have been carried on with so little knowledge or care for the highest efficiency, that no generalizations can be drawn that would compare in value with those derived from foreign plants and described so fully in the reports of the Royal Commission on Sewage Disposal and by the authors of the first three parts of this volume. The quite common use of the septic tank has, in a measure, simplified the sludge problem and with the anticipated adoption of the Emscher tank by many towns within a short time another step forward will have been taken. Horizontal tanks,

with or without chemicals, will probably continue to be used on account of local conditions and it is probable that a broader field for fine screening and drying by centrifugals will develop, but from the marked advantages in sedimentation processes carried on in conjunction with a special sludge chamber it seems probable that the Emscher tank in its present or a modified form is destined to play an important part in sewage treatment in America for some time to come.

LOCALITIES

LIST OF NAMES

INDEX

ERRATA

Page 16. Line 2 from bottom. In place of "suspened" should read "suspended."
" 19. Line 4. In place of "100" should read "1000."
" 23. Line 15. In place of "very" should read "every."
" 27. Reverse the numbers and positions of footnotes.
" 55. Under Fig. 20. In place of "the watering" should read "De-watering."
" " Last word. In place of "incineration" should read "evaporation."
" 56. Line 12. In place of "presser" should read "presses."
" 62. Line 4. In place of "2 to 3 to 1 to 2" should read "2/3 to 1/2."
" 74. Line 8. In place of "2 to 3" should read "2/3."
" " Line 9. In place of "1 to 3" should read "1/3."
" " Line 12 from bottom. In place of "9 to 10" and "1 to 10" should read "9/10" and "1/10."
" " Line 15. In place of "1720" should read "1718."
" 109. Line 10. In place of "withe" should read "with."
" 135. Line 5 from bottom. In place of "W. Oven—Travis" should read "W. Owen Travis."
" 148. Line 2 from bottom. In place of "1.9" should read "91."
" " Line 1 from bottom. In place of "2.1" should read "21."
" 183. Line 15 from bottom. In place of "Rechlinghausen" should read "Recklinghausen."
" 200. Line 7. In place of "were" should read "was."
" 201. Line 2. In place of "18,150" should read "1815."
" 204. Line 1 from bottom. In place of "Com'rs" should read "Com'n."
" 210. Line 13. In place of "pumpted" should read "pumped."
" 219. Place Table XVI at foot of page.
" 225. Line 8. In place of "40" should read "400."
" 239. In Table XXIX indent "Barking" instead of "Glasgow."
" 244. Line 10 from bottom. In place of "the Hilles" should read "Hille's."
" 251. Lines 3 and 4 from bottom in column 2. In place of "12.4 22.9" should read "12.4–22.9."
" 255. Line 13. In place of "10" should read "1.0."

Allen's Sewage Sludge.